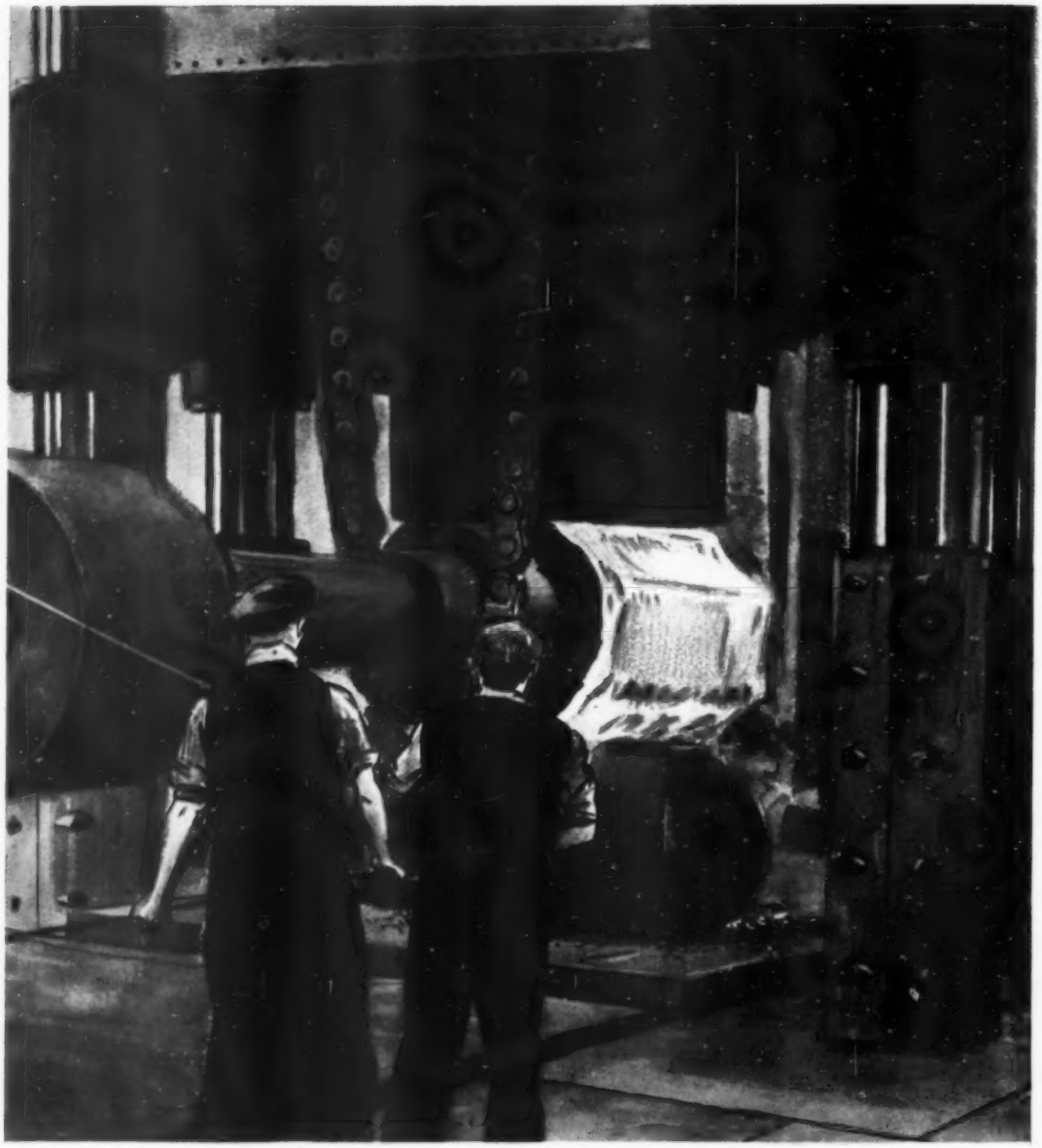
METALLURGIA

THE BRITISH JOURNAL OF METALS

Vol. 45 No. 269 MARCH, 1952 Monthly : TWO SHILLINGS

APR 11 1952

Rolling transformer sheets on the mechanized mill at the Panteg Works of Richard Thomas & Baldwins Ltd.



The illustration shows a solid Forging under a 2,700 tons Press.

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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER."

MARCH, 1952 Vol. XLV No. 269

Founded on Fact

NOWADAYS it seems that all progressive industries must possess a trade association, a research association and a means of maintaining good relations with the general public. The ironfounding industry has had its trade association for some time, and was one of the first to appreciate the value of co-operative research.

Quite recently there has been definite evidence of a growing appreciation of the advisability of keeping the public informed about the industry. When the suggestion was made by the British Iron and Steel Federation, in its December Bulletin of Statistics, that the increase in the production of iron castings, by using more pig iron and scrap, had contributed to the failure of the steel industry to produce the 16,000,000 tons which had been planned for 1951, and when, moreover, it was suggested that it would be reasonable to limit the ironfoundry output to the 1950 figure until steel output had been restored to 16,250,000 tons, vigorous protests were entered by the ironfounders. In a statement issued by the Council of Ironfoundry Associations and in letters to the Press over the signature of Mr. N. P. Newman, Chairman of the Council, it was pointed out that of the extra 237,000 tons of pig iron and scrap used by the foundries in 1951, no less than 180,000 tons was accounted for by running down stocks, and the counter suggestion was made that the real cause of the trouble had been the 1,340,000 tons decrease in the amount of imported scrap. Moreover, the Council denied the right of another industry—as represented by the British Iron and Steel Federation—to define, or attempt to define, the rate of their expansion, and therefore to interfere with the ironfounders' responsibilities to the nation.

This question of the relationship between the industry and the nation forms the basis for a booklet, "Founded on Fact," published quite recently by the Council of Ironfoundry Associations (C.F.A.), which is a member, along with the Council of Iron Producers, of the Joint Iron Council (J.I.C.). The publication of this booklet is most opportune and gives evidence of a desire for positive action regarding public relations, as distinct from the defensive course which was necessary in the iron versus steel controversy—in other words it is appreciated that it is better (and easier) to create goodwill than to eradicate ill-will.

"Founded on Fact" has been prepared by a technical journalist who, after an investigation of the industry, has had a free hand to plan its form and to accept or reject any suggestions or criticisms offered to him. The outcome is avowedly a "statement of claim" for the ironfoundry industry, true, as the author believes, in substance and in fact. The treatment of the subject is deliberately brief, so that busy men and women at the head of affairs may be able to find time to read it.

Opening with a Wellsian theme which allows the existence of some occult power which can instantly and selectively turn to dust every iron casting, wherever it may be, the author proceeds to show the extent to which civilisation would be affected by switching on this power at eight o'clock one morning. In this novel way, the important functional place which cast iron holds in the nation's activities is clearly demonstrated, and it is emphasised that this position is held not by any special privilege but by reason of the fact that nothing else will do the work done by cast iron so well or so suitably, either from a technical or an economic point of view.

In his survey, the author, before discussing the activities of the industry in 1951, deals in turn with its history, casting production, labour, research and development for service. The last named section probably lies closest to the principal theme of the booklet as may be seen from the following introductory paragraph—"Can the public feel satisfied that in the ironfounding industry it has a service as well as a profit-making contribution to the Welfare State? In other words, have the ironfounders a sense of responsibility to the community as a whole, as well as to their workpeople and the shareholders?" After a fairly extensive study of the facts as set out in the official records of the Joint Iron Council and the Council of Ironfoundry Associations—records which are subject to Governmental eyes, to official scrutiny and checking—the author believes the answer to these questions is a definite "yes."

In one of its earliest documents, a report presented in 1946 to the Minister of Supply, the J.I.C. states its aim as ". . . progressively to increase overall efficiency as the outcome of collective examination of every aspect of a very complex industry . . . every effort will be made to develop along lines which will lead to the best combination of low costs and high quality." In September, 1948, the C.F.A. set up a Development Panel in fulfilment of a pledge in a J.I.C. statement on development policy. The Panel had the task of studying operating conditions in selected foundries, and of examining problems of efficiency both technically and managerially. It had also to examine special aspects of efficiency, including economy in the use of raw materials, better utilisation of labour, etc., and to keep in touch with the latest technical developments at home and abroad. A further important duty has been to press on with the implementation of the Garrett Report on working conditions which was published in 1947.

The results in higher production, an increased labour force, and improved working conditions, testify to the effectiveness with which the Panel has carried out its allotted task, and while it cannot be doubted that the people who invest their brains, muscles and money in the industry benefit from this drive for all-round betterment, acceptance of the importance of iron castings to the community must mean that all benefit from the increased efficiency.

Turkish Steelworks Reconstruction Order Received by British Firm

In the face of strong German competition, Davy and United Engineering Company Limited have received a further major export order in the shape of a contract from Karabuk Iron and Steel Works in Turkey for the large-scale extension and modification of their existing 28 in. blooming and section mill plant. This particular plant was in fact originally built by Davy-United just prior to the outbreak of the 1939-45 War; in addition, apart from producing its own considerable range of finished products the plant was also designed to feed 12 in. and 16 in. merchant mills built by Duncan Stewart and Company Limited before their entry into the Davy-United Group. The new contract now received will involve the supply by Davy-United of more than 1,000 tons of new mill machinery and hydraulic equipment.

Karabuk Iron and Steel Works, situated in Northern Turkey about 50 miles from the Black Sea, is the only integrated steel plant in Turkey and therefore stands in highly important relationship to the economy of that country: it uses home-produced coke and ores. The extensive reconstruction of the plant which is now being undertaken has as its primary object the raising of output to approximately twice its present annual level, with obvious consequent benefit to Turkey's other industries and her national standard of life generally.

The present reconstruction calls first of all for the conversion of a previous 3-high blooming mill stand to a 2-high blooming stand, involved in which operation will be the supply of new ingoing main table; electrically-operated universal side-guard manipulators on the ingoing side designed to match a future mill having rolls 6 ft. long in the barrel; new breastrollers, pinion housing, pinions, main coupling, coupling spindles and boxes; a modified shear approach table; and an automatic pressure grease lubrication system. Apart from an annual output of 190,000 tons of rails, sleepers, billets, sheet bar, pit arches and other sections the converted plant will also be expected to produce 10,000 tons of plate a year. For this purpose, the blooming mill delivery table will be suitable for handling slabs and will embody an electrically-operated device for broad-siding operations. Initially the plant will use the existing ingot of 2·2 tons in weight, but design provision is being made to allow for the handling of 3 ton ingots projected in the future.

The blooming mill stand will be followed by a 3-stand 2-high section mill train for which existing stands will be considerably modified. The remodelled section mill will also be re-positioned to permit of a straight-line feed direct from the blooming mill down to the first roughing stand. Extensive modifications to the section mill stands will include the provision of new spindles and balance gear, electric screwdown and index gear, four "Williams" manipulators, extensions to skid gear and considerable additions to and adaptation of roller tables. Considerable sections of the roller tables will include individually motor driven roller units; tables will run on roller bearings almost throughout. Two new electric hot shears, both with blade loads of 250 tons and designed to deal with sheet bar and billets respectively, will be built and will be supplied along with stop and measuring gear and deflecting tables. An automatic pressure grease lubrication system will be installed while a new auxiliary hydraulic system for roll balance will call for a 50 gallon air-loaded accumulator with pump and compressor.

In the complex undertaking of reconstruction a priority requirement will be the very minimum interruption to production in the plant. Davy-United have, therefore, also been entrusted with the planning and co-ordination of the delivery and erection of all plant required under this new development scheme.

Zinc Alloy Die Casters Association

Annual General Meeting

Sixty-five representatives of member firms of the Zinc Alloy Die Casters Association attended the Annual General Meeting and luncheon in Birmingham on 15th January, 1952. The Meeting paid tribute to the memory of Mr. L. Whitworth of the Chase Non-Ferrous Metals Company, who had been one of the pioneers of die casting in Great Britain.

The first duty undertaken by the Chairman for 1952–53, Mr. F. G. Woollard of the Birmingham Aluminium Casting (1903) Co. Ltd., was to propose a vote of thanks to the retiring Chairman, Mr. J. W. Cartlidge of Dyson & Co. Enfield (1919) Ltd., who would continue to serve as Deputy Chairman for the next two years. Mr. Cartlidge had piloted the Association through the difficult period of the metal shortage from which it had emerged with new strength.

After referring to the work of Mr. R. Lewis Stubbs and the Zinc Development Association, who acted as secretaries to Z.A.D.C.A., Mr. Woollard introduced the Guest Speaker, Mr. D. H. Bramley, Head of the Department of Industrial Administration at the Birmingham College of Technology.

Mr. Bramley discussed the training of personnel for managerial positions in industry. He listed the requirements of a good manager under five headings: personal qualities; experience under effective management; experience of the job; technical knowledge; and a knowledge of management technique. He compared the limited programme of management education in Great Britain with the well established courses of the United States, which he had recently visited as a member of a Productivity Team on the Training of Supervisors. A vote of thanks was proposed by Dr. Street of Fry's Diecastings Ltd.

In the report on the work of the Association during 1951 attention was drawn to the satisfactory increase in membership during the year, to the improvement in the availability of supplies of zinc alloy for die casting, to the work done by Z.A.D.C.A. representatives on various Government and other Committees, to the teams which had been sent abroad to collect information on die casting techniques there and to the liaison established with similar bodies in the U.S.A. and on the Continent. The work of the Association's Technical and Publications Committees was reported on by members of the Z.D.A. staff and covered a large variety of topics from die lubricants to advertising.

The meeting concluded with a showing of a film recently produced by one of the largest American die casting firms to explain the process to their clients and prospective clients.

Northern Aluminium Co., Ltd., announce that the address of their Manchester Area Sales Office is now: 75, Piccadilly, Manchester, 1. (Tel. Central 5479).

Some Observations on the Determination of Residual Stresses in Cylindrical Metal Bodies by Sachs' Boring Method

By R. A. Dodd, Ph.D., M.Sc.

PROBABLY the most widely used mechanical method giving a three dimensional evaluation of the residual stresses in metals is that originally devised by G. Sachs[1] and which is applicable to solid cylinders or thick-walled tubing. In this method a hole is drilled up the centre of the cylinder and the cylinder is then bored out in steps. The dimensions of the cylinder, i.e., external diameter and length, are measured accurately after each successive step in the machining operation, and the residual stresses originally present in the cylinder are given by the equations

$$S_L = \frac{E}{1-\nu^2}\left\{ (F_b - F)\ \frac{d\Lambda}{dF} - \Lambda \right\}$$

$$S_T = \frac{E}{1-\nu^2}\left\{ (F_b - F)\frac{d\theta}{dF} - \left(\frac{F_b + F}{2F}\right)\theta \right\}$$

$$S_R = \frac{E}{1-\nu^2}\left\{ \left(\frac{F_b - F}{2F}\right)\theta \right\}$$

where

E = Modulus of Elasticity.
ν = Poisson's Ratio.
F_b = Total Cross Sectional Area.
F = Area of Bored-out Cross Section.
Λ = $(\lambda + \nu\delta)$ λ and δ are the longitudinal and
θ = $(\delta + \nu\lambda)$ circumferential strains, respectively.

S_L, S_T and S_R are the longitudinal, tangential and radial stress components respectively at a point r_1, on the cross section where $F = \pi r_1^2$

The differentials $\frac{d\Lambda}{dF}$ and $\frac{d\theta}{dF}$ are determined by drawing tangents to the curves obtained by plotting Λ and θ against F.

Earlier workers[2] who used this method of residual stress analysis measured the strains by means of micrometers and vernier calipers, but, as the strains are frequently of the order $10^{-5}/10^{-4}$ and are difficult to measure accurately by this method, electrical resistance strain gauges have lately been applied to Sachs' method.

In a recent review of mechanical methods for the determination of residual stresses in metals, H. Ford[3] emphasises the superiority of the method over earlier methods such as those of E. Heyn[4] and other workers, and in view of its probable use in future researches it is important that possible errors to which the method may be subject be considered.

In the following paper the method is fully discussed, and, on the basis of experimental results, an experimental technique is suggested which appears to obviate major errors and to yield reliable results.

General Discussion

Possible causes of error in stresses evaluated by Sachs' method may be grouped under two main headings.

(1) *Errors in the measured strains which are inherent to the use of electrical resistance strain gauges.* Resistance strain gauge technique has been adequately discussed in many recent papers and, on the assumption that standard recommended technique is employed, errors due to "creep" and "zero-drift" are very small. The term "zero-drift" refers to the slow and erratic drifting of the galvanometer zero, and has been shown to be due to the presence of moisture in the gauges. J. Edwards[5] states that over short periods (2 hours) it is unsatisfactory to work with gauges of less than 15 megohms insulation resistance, whilst over long periods (days) the insulation resistance should be at least 70 megohms. E. Jones[6] has shown that, assuming good sticking technique, adequate waterproofing, etc., the creep over the first 24 hours for a continuously maintained strain of 0·25% may amount to 3×10^{-5}. This result was obtained using a cupro-nickel acetate cement. Under similar conditions the zero drift should not exceed 10^{-5}. Creep results from traces of unevaporated solvent in the cement which leaves the cement in a plastic condition and causes the strain readings to creep towards zero. F. Aughtie[7] states that if the gauges can be baked on to the specimen, then creep is unknown under those conditions. Unfortunately, in residual stress studies the gauges cannot, in general, be baked on, although this must depend on the material of the specimen and, for example, would undoubtedly be possible in the case of steel specimens. Furthermore, it should be noted that once the boring operations have commenced, the gauge and cement are in a state of perpetual strain which increases as boring proceeds. In view of the fact that the strains to be measured may be very small, it is of some importance that the tests should extend over as short a time as possible.

It appears from published work concerning Sachs' method that the normally used technique entails repeated soldering and unsoldering of the gauge leads—i.e., in between each successive boring operation. It will be realised that the whole operation must of necessity extend over a considerable period of time, as, apart

1 Sachs, G., *Z. Metallkunde*, 1927, **19**, 352.
2 Sachs, G. and Espey, G., *Iron Age*, 1941, **148** (12), 63.
3 Ford, H., "Symposium on Internal Stresses in Metals and Alloys," Institute of Metals, 1947, p. 3.
4 Heyn, E., *J. Inst. Metals*, 1914, **12**, 3.
5 Edwards, Discussion following paper by Aughtie, F., *Trans. Inst. of Marine Engineers*, **57** (4), May, 1946.
6 Jones, E., "The Measurement of Stress and Strain in Solids," *Physics in Industry*, Institute of Physics, 1948, p. 1.
7 Aughtie, F. As (5) above.

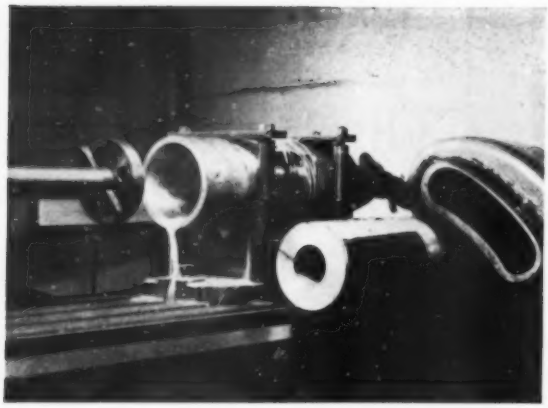


Fig. 1.—Cylinder clamped in position for boring.

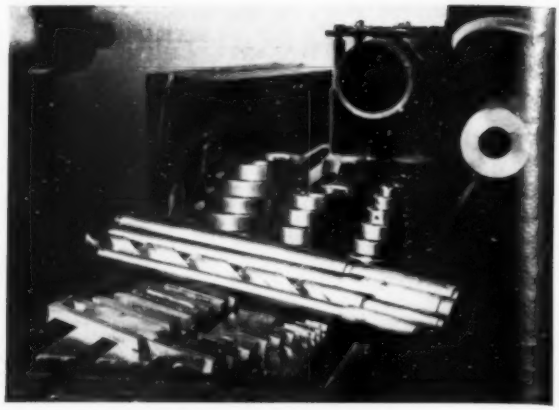


Fig. 2.—Selection of tools used for drilling and boring.

from time consumed during the repeated soldering and unsoldering operations, some further considerable time must elapse between successive measurements in order that adequate allowance is made for temperature compensation. H. Ford[3] has pointed out that, for accurate results in applying electrical resistance strain gauges to Sachs' method, the measurements must extend over several days, and possibly weeks, in order to minimise temperature errors.

In view of the previous remarks on the desirability of carrying out the tests in the shortest possible time, it can be seen that some improvements in experimental technique are desirable.

It may also be noted that the soldering operations introduce a resistance change which will be interpreted as a strain. A. E. MacPherson[8] has shown that such changes in resistance approximate to an error in stress of about 80 lb./sq. in. in a magnesium alloy. Assuming $E = 6{\cdot}5 \times 10^6$ lb./sq. in. this is equivalent to a strain of $1{\cdot}2 \times 10^{-5}$, and represents an error of approximately 10% in the measured individual strains in the case of quenched aluminium alloy billets. These results are discussed later and, as these billets contain high residual stresses, it will be realised that in other cases the percentage error may be considerably higher.

(2) *Errors due to the introduction of extraneous residual stresses during machining of the specimen.* R. Weck[9] has drawn attention to the fact that standard experimental techniques of applying mechanical methods of residual stress measurement do not, in general, exist,

8 MacPherson, A. E., *Exp. Stress Analysis*, 1944, **2** (1), 200.

9 Weck, R., "Symposium on Internal Stresses in Metals and Alloys," Institute of Metals, 1947, p. 386.

TABLE I.—RESIDUAL STRESS MEASUREMENTS ON 3 IN. DIAMETER RR.59 BILLET QUENCHED FROM 450° C. NORMAL BORING. $F_b = 7{\cdot}07$

Diameter of Bored-out Cross Section in.	Area of Bored-out Cross Section F sq. in.	λ $\times 10^5$	δ $\times 10^5$	A $\times 10^5$	θ $\times 10^5$	$\frac{dA}{dF}$ $\times 10^5$	$\frac{d\theta}{dF}$ $\times 10^5$	Stress in tons/sq. in.	
								Longitudinal	Tangential
0·91	0·64	10·8	8·2	13·5	11·8	19·5	17·0	5·87	2·01
1·3	1·33	22·5	18·6	28·7	26·1	19·5	17·0	4·37	0·80
1·7	2·27	38·0	27·0	47·0	39·7	19·5	17·0	2·45	0·01
2·1	3·46	56·3	40·2	69·7	59·0	19·5	17·0	0·04	−1·49
2·3	4·15	63·4	49·3	79·8	70·4	11·5	13·5	−2·43	−2·93
2·5	4·91	68·5	55·5	87·0	78·3	7	8	−3·78	−4·11
2·7	5·73	71·4	59·7	91·3	83·5	3	5	−4·58	−4·47

TABLE II.—RESIDUAL STRESS MEASUREMENTS ON 3 IN. DIAMETER RR.59 BILLET QUENCHED FROM 450° C. NORMAL BORING. $F_b = 7{\cdot}07$

Diameter of Bored-out Cross Section in.	Area of Bored-out Cross Section F sq. in.	λ $\times 10^5$	δ $\times 10^5$	A $\times 10^5$	θ $\times 10^5$	$\frac{dA}{dF}$ $\times 10^5$	$\frac{d\theta}{dF}$ $\times 10^5$	Stress in tons/sq. in.	
								Longitudinal	Tangential
0·91	0·64	12·4	9·2	15·5	13·3	19·5	16·0	5·77	1·21
1·3	1·33	23·4	16·7	29·0	24·5	19·5	16·0	4·36	0·76
1·7	2·27	38·8	27·4	47·9	40·3	19·5	16·0	2·40	−0·32
2·1	3·46	56·7	40·1	70·1	59·0	17·0	15·0	−0·46	−1·87
2·3	4·15	64·5	46·7	80·1	68·2	11·5	11·0	−2·44	−3·16
2·5	4·91	69·5	52·3	86·9	75·5	7·0	8·5	−3·77	−3·88
2·7	5·73	72·2	55·8	90·8	79·9	2·5	5·5	−4·59	−4·38

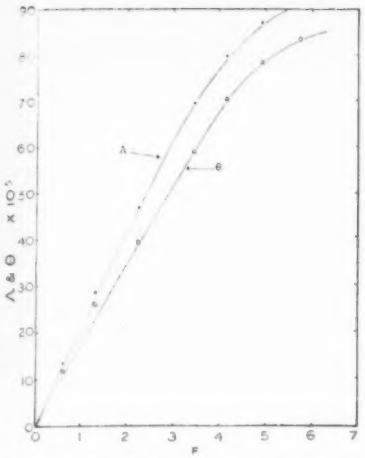


Fig. 3.—Strain/cross-section curves for 3 in. diameter × 12 in. long RR.59 billet, quenched from 450° C. Normal boring.

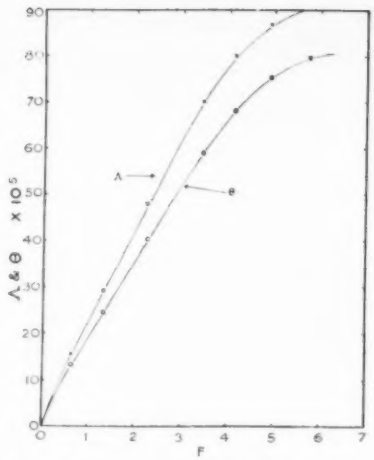


Fig. 4.—Strain/cross-section curves for 3 in. diameter × 12 in. long RR.59 billet, quenched from 450° C. Normal boring.

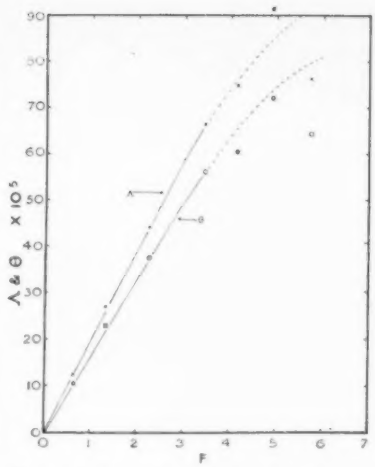


Fig. 5.—Strain/cross-section curves for 3 in. diameter × 12 in. long RR.59 billet, quenched from 450° C. Vibration and chattering of cutting tools introduced.

and major points to which attention should be given are therefore frequently overlooked. All mechanical methods depend on the subdivision of the specimen, usually by machining, and although it is a well-known fact that the machining of metals, except under special circumstances, gives rise to residual stresses, no information is available indicating to what extent these stresses affect accurate measurement of the original residual stresses.

Experimental Work

Having regard to the above considerations an experimental technique has been developed which appears to eliminate the possible errors enumerated above. This technique has been applied to aluminium alloy solid cylinders of approximate dimensions 12 in. length × 3–6 in. diameter as follows:

The cylinder is clamped in a horizontal position in a cast iron V-block (Fig. 1) bolted to the bed of a milling machine fitted with a universal head, and, after being drilled down the centre, is bored out in steps by means of boring bars and interchangeable cutting tools (Fig. 2). In order to ensure rigidity of the boring bars they are equipped with pilot tools screwed on to the bar immediately in front of the cutting tool. These pilot tools are a reasonably close fit in the bored holes giving complete freedom from vibration and resultant chattering. The specimen is maintained at room temperature or thereabouts during the machining operation by a rapid flow of coolant through the cylinder, the arrangement for which can be clearly seen in the photograph. This also serves to wash out all drillings and allows uninterrupted boring to proceed. Holes are drilled in the pilot tools to allow passage of the coolant. Using this technique, the time occupied by a single machining operation, and in subsequently allowing the specimen and dummy specimen to attain the same temperature (assessed by the observation of galvanometer drift) is of the order of 2 hours. As strain measurements are normally taken over each 10% of the bored-out cross section, it follows that the series of measurements is completed in about three days.

In Tables I–IV are shown results obtained by applying Sachs' method to four aluminium alloy (R.R.59) billets of 3 in. diameter and 12 in. length.* Billets 1–3 were end-quenched from 450° C. in water at 20° C., while billet 4 was heat treated at 400° C. for 30 min. and furnace cooled. In the case of billets 1, 2 and 4, the machining technique described above was applied, while in the case of billet 3 vibration and chattering of the cutting tools was deliberately introduced by dispensing with the use of the pilot tools.

* The strains were measured with 200 ohm British Thermostat self-adhesive gauges in conjunction with a slidewire type Wheatstone Bridge.

TABLE III.—RESIDUAL STRESS MEASUREMENTS ON 3 IN. DIAMETER RR.59 BILLET QUENCHED FROM 450° C. VIBRATION AND CHATTERING OF CUTTING TOOLS INTRODUCED

Dia. of Bored-out Cross Section in.	Area of Bored-out Cross Section — F sq. in.	λ × 10^5	δ × 10^5	A × 10^5	θ × 10^5
0·91	0·64	10·1	7·2	12·5	10·6
1·3	1·33	21·6	15·6	26·8	22·8
1·7	2·27	35·5	25·6	44·0	73·4
2·1	3·46	53·7	38·2	66·4	56·1
2·3	4·15	61·5	40·1	74·9	60·6
2·5	4·91	75·7	46·9	91·3	72·1
2·7	5·73	61·7	43·8	76·3	64.4

TABLE IV.—RESIDUAL STRESS MEASUREMENTS ON 3 IN. DIA. RR.59 BILLET FURNACE COOLED FROM 400° C. NORMAL BORING

Dia. of Bored-out Cross Section in.	Area of Bored-out Cross Section — F sq. in.	λ × 10^5	δ × 10^5	A × 10^5	θ × 10^5
0·91	0·64	0·10	−0·7	0·1	−0·7
1·3	1·33	0·7	−0·6	0·5	−0·4
1·7	2·27	0·2	−0·4	0·1	−0·3
2·1	3·46	0·2	−0·1	0·2	0·0
2·5	4·91	1·7	−0·7	1·5	−0·1

TABLE V.—RESIDUAL STRESS MEASUREMENTS ON 4 IN. DIAMETER, 12 IN. LONG, SUPER-DURALUMIN BILLET QUENCHED FROM 525° C.

Diameter of Bored-out Cross Section in.	Area of Bored-out Cross Section F sq. in.	λ $\times 10^5$	δ $\times 10^5$	A $\times 10^5$	θ $\times 10^5$	$\frac{dA}{dF}$ $\times 10^5$	$\frac{d\theta}{dF}$ $\times 10^5$	Stress in tons/sq. in.	
								Longitudinal	Tangential
0·91	0·64	13·7	10·1	17·1	14·7	—	—	—	—
1·3	1·33	31·5	24·0	39·5	34·5	—	—	—	—
1·7	2·27	54·0	41·1	67·7	59·1	—	—	—	—
2·1	3·46	78·6	66·5	100·8	92·7	—	—	—	—
2·5	4·91	113·0	87·5	142·2	125·2	—	—	—	—
2·9	6·61	150	115	188	165	—	—	—	—
3·3	8·55	187	147	236	209	22·5	20·0	−7·67	−9·34
3·5	9·62	201	162	255	229	15·0	15·0	−11·09	−11·55
3·7	10·80	209	172	266	242	5·0	7·5	−13·50	−13·08

Longitudinal stress at surface obtained by extrapolation = − 14·8 tons/sq. in.
Tangential stress at surface obtained by extrapolation = − 13·9 tons/sq. in.

In Figs. 3–6 the measured strains are shown plotted against the bored out cross section. It will be observed that the strain/cross section curves shown in Figs. 3 and 4 are practically superimposable and show the excellent reproducibility of the method. The corresponding stresses are shown in Fig. 7.

The strain/cross section curve in Fig. 5 is in very close agreement with the curve shown in Figs. 3 and 4 except for the upper portion of the curves which correspond to the boring out of a relatively thin walled cylinder. The points in these portions of the curves show severe scattering, and in view of the fact that this scattering was not observed when the normal machining technique was used, it must be inferred that it is caused by stresses induced by the machining operation. It may be noted that the scattering becomes appreciable when the wall thickness is of the order of $\frac{1}{2}$ in., and it appears, therefore, that machining stresses may cause errors when dealing with thin walled tubing. In such cases it may be necessary to adopt an alternative method of removing the metal—e.g., pickling in acid. In the case of solid cylinders, the negligible effect of machining stresses is further illustrated by reference to Fig. 6. The measured strains obtained by boring out the annealed billet are so small that it is not possible to interpret them in terms of stress.

In the derivation of his stress/strain equations, Sachs makes the assumption that the removal of a layer of stressed material produces an equal change of longitudinal stress at all points on the cross section. This assumption is theoretically justified only when the length is at least three times the diameter. Various investigations have employed specimens in which this requirement is not fulfilled, and in such a case the boring method is theoretically inapplicable.

In Tables V and VI are shown results obtained by applying Sachs' method to Duralumin billets which had been end quenched from 525° C. in water at 20° C. The billets were of length 12 in. and 4 in., the diameter being 4 in. in each case—i.e., ratio of length to diameter = 3 : 1 and 1 : 1, respectively. The strain/cross section curves are given in Figs. 8 and 9. The maximum longitudinal and tangential stresses (at the surface) were obtained by extrapolating the stress/cross section curve to 100% cross section, and are quoted in Table VII together with the longitudinal and tangential surface stresses determined, prior to boring, by the X-ray analysis method. The X-ray apparatus and technique were identical with those described by Frommer and Lloyd[10] and a selection of the X-ray patterns obtained is shown in Fig. 10. Each billet was examined at three points situated 120° apart and half way along its length. Both longitudinal and tangential components were determined at each point.

It will be observed that the results obtained by the boring and the X-ray methods are in reasonably good

10 Frommer, L. and Lloyd, E. H., *J. Institute of Metals*, 1944, **70**, 91.

TABLE VI.—RESIDUAL STRESS MEASUREMENTS ON 4 IN. DIAMETER, 4 IN. LONG, SUPER-DURALUMIN BILLET QUENCHED FOR 525° C.

Diameter of Bored-out Cross Section in.	Area of Bored-out Cross Section F sq. in.	λ $\times 10^5$	δ $\times 10^5$	A $\times 10^5$	θ $\times 10^5$	$\frac{dA}{dF}$ $\times 10^5$	$\frac{d\theta}{dF}$ $\times 10^5$	Stress in tons/sq. in.	
								Longitudinal	Tangential
0·91	0·64	8·1	5·8	10·0	8·5	—	—	—	—
1·3	1·33	16·8	12·2	20·9	17·8	—	—	—	—
1·7	2·27	30·2	23·7	38·1	33·8	—	—	—	—
2·1	3·46	41·8	33·9	53·1	47·8	—	—	—	—
2·5	4·91	64·0	49·0	80·3	70·3	—	—	—	—
2·9	6·61	83·2	67·1	105·6	94·8	—	—	—	—
3·3	8·55	107	83·2	134·7	118·9	14·0	10·0	−4·15	−5·62
3·5	9·62	118	90·7	148·2	130·0	11·0	9·0	−6·04	−6·46
3·7	10·80	125	96·0	157	137·6	6·0	6·0	−7·67	−7·25

Longitudinal stress at surface obtained by extrapolation = −9·0 tons/sq. in.
Tangential stress at surface obtained by extrapolation = −7·9 tons/sq. in.

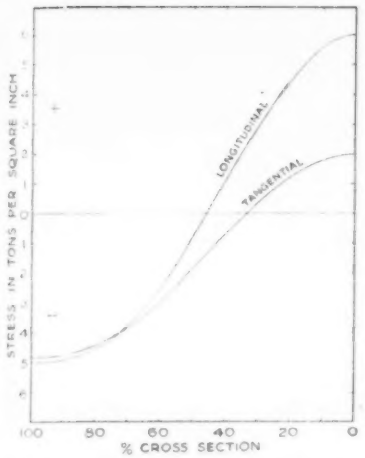


Fig. 7.—Stress corresponding to strains plotted in Figs. 3 and 4.

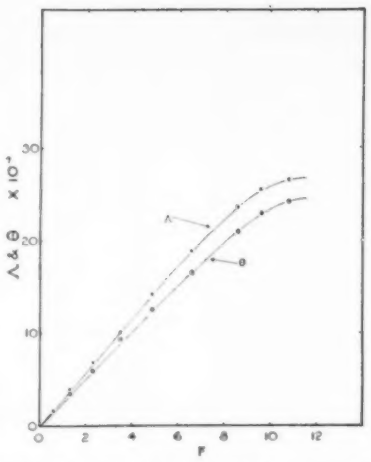


Fig. 8.—Strain/cross-section curves for 4 in. diameter × 12 in. long Super-Duralumin billet quenched from 525° C.

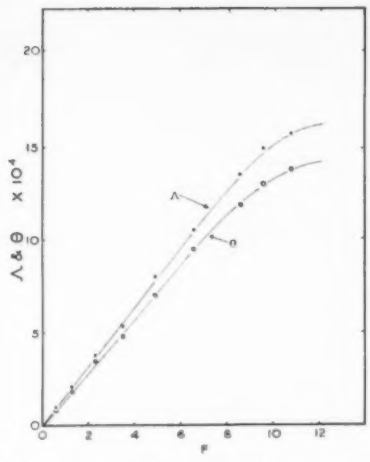


Fig. 9.—Strain/cross-section curves for 4 in. diameter × 4 in. long Super-Duralumin billet quenched from 525° C.

agreement. It, therefore, appears that Sachs' method is applicable to cases where the length/diameter ratio is 1 : 1, and it may be that the method could be used for even smaller ratios. It would be of interest to know at what ratio the method finally breaks down.

C. S. Barrett[11] lists certain criteria to which results obtained by Sachs' method should conform. These are :

(1) On the plot of longitudinal stress versus cross-section of the bore, the area under the curve representing compression should be equal to the area under the curve representing tension.

(2) Equal compressive and tensile areas should also be found in the tangential stress plot.

(3) The radial stress is zero at inner and outer surfaces.

Thus Barrett assumes that the loads on a cross section corresponding to the longitudinal, tangential and radial stresses are each separately zero. This is certainly true for the longitudinal load, but needs further investigation for the case of the tangential and radial loads as the stresses in question vary throughout the cross section.

The longitudinal stress component is given by

$$S_L = \frac{E}{1-\nu^2}\left\{(F_b - F)\frac{d\Delta}{dF} - \Delta\right\}$$

If we assume a linear relationship between the measured strains and the bored out section (this has been observed by some workers)

$$\text{i.e.} \qquad \frac{d\Delta}{dF} = C_1$$

we can write

$$S_L = \frac{E}{1-\nu^2}\left\{\left(F_b - F\right)C_1 - C_1 F\right\}$$

$$= C_2 \cdot \left\{C_1 F_b - 2\,C_1 F\right\}$$

Where the stress curve cuts the axis of cross section,

i.e. $S_L = O$

$$C_1 F_b = 2\,C_1 F$$

or $$F_b = 2F$$

i.e., the curve cuts at 50% cross section.

11 Barrett, C. S., *Exp. Stress Analysis*, 1944, **2** (1), 147.

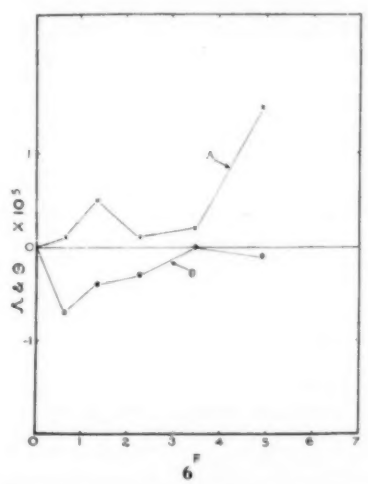
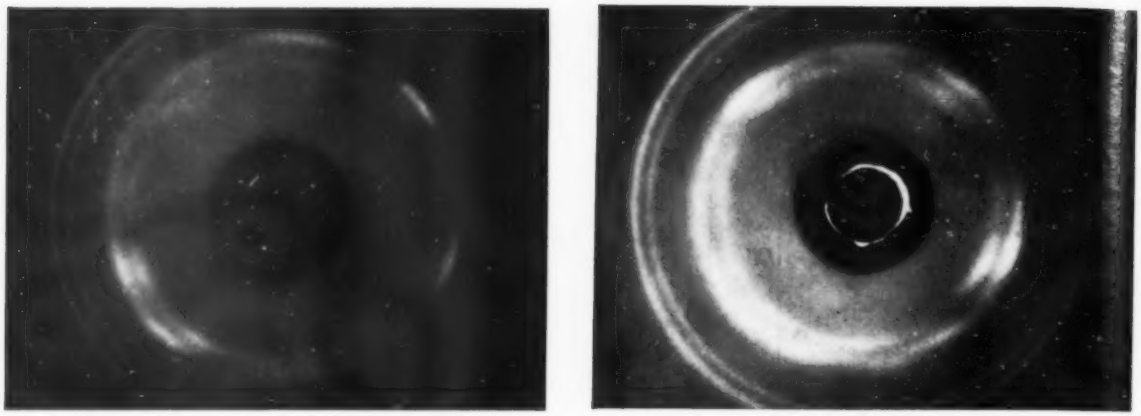


Fig. 6.— Strain/cross-section curves for 3 in. diameter × 12 in. long RR.59 billet furnace cooled from 400°C. Normal boring.

TABLE VI.—COMPARISON OF STRESSES OBTAINED BY SACHS' AND X-RAY METHODS

Length of Billet	Sachs' Method		X-ray Analysis	
	Maximum Longitudinal Stress (Compressive)	Maximum Tangential Stress (Compressive)	Maximum Longitudinal Stress (Compressive)	Maximum Tangential Stress (Compressive)
4 in. ..	9·0 tons/sq. in.	7·9 tons/sq. in.	9·8, 8·9, 8·8 } 9·2 Tons/sq. in.	10·6, 9·0, 10·3 } 10·0 Tons/sq. in.
12 in. ..	14·8 tons/sq. in.	13·9 tons/sq. in.	16·8, 16·1, 16·6 } 16·5 Tons/sq. in.	72·9, 14·2, 14·4 } 13·8 Tons/sq. in.



(a) Incident beam normal to specimen surface. (b) Incident beam inclined at 45° to specimen surface.

Fig. 10.—X-ray stress measurement (tangential stress component) of quenched 12 in. long Duralumin billet. Back reflection photographs showing aluminium and silver calibration (511) α_1, α_2 reflections. (Note the considerable contraction of the aluminium ring in the inclined exposure—high internal stress).

The tangential stress component is given by

$$S_T = \frac{E}{1-\nu^2}\left\{\left(F_b - F\right)\frac{d\theta}{dF} - \left(\frac{F_b+F}{2F}\right)\theta\right\}$$

$$\text{or} \quad S_T = C_2\left\{(F_b - F)\,C_1 - \left(\frac{F_b+F}{2F}\right)C_1\,F\right\}$$

$$= C_2\left\{(F_b - F)\,C_1 - \tfrac{1}{2}\,C_1\,(F_b + F)\right\}$$

Where $S_T = 0$

$$2C_1\,F_b - 2C_1\,F = C_1\,F_b + C_1\,F$$

$$\text{or} \quad F_b = 3F$$

i.e., the curve cuts at $33\frac{1}{3}\%$ cross section.

The radial stress component is given by

$$S_R = C_2\left\{\left(\frac{F_b - F}{2F}\right)\cdot C_1\,F\right\}$$

Where $S_R = 0$

$$F_b = F$$

i.e., the curve cuts at 100% cross section.

Thus it can be seen that the second of Barrett's criteria does not hold. In cases where the relationship between strain and bored-out section is not linear, it is doubtful if any tests are applicable to results obtained by Sachs' method in order to verify their accuracy.

Conclusion

In the foregoing paper Sachs' method of evaluating stresses in cylindrical metal bodies is discussed, and an experimental technique is suggested which is suitable for application to solid cylinders or thick-walled tubing.

Results are quoted which show that, providing the machining of the cylinder is carefully performed, the measured strains are substantially free from errors introduced by the machining process. This conclusion is based on the reproducibility of results obtained from like specimens subjected to identical treatments, and from tests on stress relieved specimens.

There is, however, some evidence to show that machining stresses may affect the measured strains obtained by boring out thin-walled cylinders (wall thickness $\frac{1}{2}$ in.), and it is suggested that in such cases removal of the metal by chemical methods is preferable. Further work on this point is desirable.

Errors due to inaccuracies of strain gauge readings can be minimised by adopting recommended techniques, but it is believed that the experimental method described above represents an advance on previous methods in that the measurements can be completed in a relatively short space of time, thus minimizing "creep" and "zero-drift" errors.

X-ray stress measurements on billets which were afterwards examined by Sachs' method are quoted. The good agreement between the stresses obtained by the two methods offers further proof of the reliability of Sachs' method, and the applicability of the method to cylinders which have a length/diameter ratio of as low as 1 : 1 is demonstrated.

Certain theoretical aspects of the method are discussed and revised.

Acknowledgment

Thanks are due to Messrs. Rolls Royce, Ltd. for the use of X-ray diffraction apparatus enabling the X-ray stress measurements to be performed.

Symposium on Mineral Dressing

ORGANISED by The Institution of Mining and Metallurgy, a Symposium on Mineral Dressing will be held at the Imperial College of Science and Technology (Royal School of Mines) on Tuesday, Wednesday and Thursday, 23rd, 24th and 25th September, 1952. The purpose of the Symposium is to discuss recent advances in the field of mineral dressing, and over 30 short papers are being prepared to form the basis for the discussion.

The Symposium is open to all interested persons, whether or not they are members of the Institution. Anyone wishing to attend, or who would like to receive further information, should write to the Secretary, The Institution of Mining and Metallurgy, Salisbury House, Finsbury Circus, London, E.C.2.

The Influence of Structure on Hardness with Special Reference to Steels

By H. A. Unckel

Communication from The Finland Institute of Technology, Helsinki

The way in which hardness is related to structure in the case of alloys which have particles or grains of a second, harder, phase present in the matrix has not received a great deal of attention. The author discusses this question and gives details of experimental results obtained with a number of steels, particular attention being devoted to a hyper-eutectoid plain carbon steel and a high chromium die steel.

INCREASE in hardness in alloys can be achieved in a number of ways. These include (1) the formation of a solid solution; (2) precipitation hardening; (3) transformation hardening; (4) the formation of a superstructure in the lattice; and (5) the formation of a second, harder, phase in the structure. In the first four cases, the increase in hardness over that of the unalloyed base metal is due to lattice strains which tend to hinder plastic glide.

In solid solutions, the strains originate in the different sizes and binding forces of solute and solvent atoms. The hardness increase varies with different alloys: with copper zinc alloys, for example, the hardness rises to two or three times that of unalloyed copper. Precipitation hardening of super-saturated solid solutions creates very high local lattice strains, which are greatest in the early stages of precipitate formation, i.e., before the precipitate is visible microscopically. Aluminium alloys of the Duralumin type and copper-beryllium alloys—the latter with a hardness increase from 80–400 Brinell—are examples of precipitation hardening alloys. Phase transformation, resulting in the precipitation of a harder constituent, leads to a hardness rise if the new phase is present in greater amounts; this will be treated later. The enormous effect met with in the hardening of steels is, however, due to high lattice strains caused by the presence of carbon in supersaturated solution in alpha iron, i.e., martensite. Even with superlattice formation, as with the gold-copper alloys, the high hardness values obtained after quenching and tempering, or after slow cooling, result from high lattice strains caused by the ordered arrangement of solute and solvent atoms.

In the case of the last-named way in which hardness increase can be achieved, by the presence of particles or crystals of a second phase which in themselves are harder than the matrix, the conditions involved have hardly been investigated. Examples of this type of structure include those consisting of pearlite—a mixture of ferrite and carbide whose hardness values differ by a factor of seven; mixtures of ferrite and pearlite in steels of different carbon content and, accordingly, different hardness; copper-aluminium and copper-zinc alloys with alpha plus beta structures; aluminium-silicon alloys; and the powder metallurgical copper-tungsten mixtures. According to Masing,[1] the hardness of a mixture of two phases is approximately proportional to their relative amount, and with precipitation from a supersaturated solution the solid solution is harder than the structure after precipitation. In a previous paper by the author,[2] some of the basic principles regarding the relation between structure and properties of alloys containing particles of a harder phase were developed. It was found that hardness and strength vary with the amount of the harder phase according to an exponential law.

With steels of different composition and treatment, several of the afore-mentioned hardness-increasing phenomena can be studied: pro-eutectoid separation of ferrite or carbide in hypo- and hyper-eutectoid steels, respectively; eutectoid formation of carbide in pearlitic steels, the lamellar spacing in the pearlite depending on the cooling conditions; transformation to martensite on quenching; the changes occurring during tempering; and the influence of isothermal treatments. In this article, reference is made to work on a number of steels. The sections on hypo-eutectoid and eutectoid steels are taken from earlier work: further experiments were carried out with a hyper-eutectoid carbon steel and a high chromium steel, with the object of amassing further data in this new field.

Hypo-eutectoid Steels

The structure of these steels in the annealed condition consists of ferrite and pearlite, the relative amounts depending mainly on the carbon content, although the ratio does depend on the cooling rate, higher cooling rates resulting in somewhat less ferrite. The hardness and other properties of the ferrite and pearlite can be studied with specimens of such composition (i.e. carbon content) that the structure is entirely ferritic or pearlitic. Micro-hardness testing, on the other hand, provides an excellent and elegant means for studying the hardness of the structural constituents "in situ" with alloys of different composition. Steels with 0·15%, 0·35%, 0·45% and 0·6% carbon were treated either by cooling at different rates from the austenitizing temperature, or by isothermal treatment in a lead bath: in this way, different amounts and arrangements of the ferrite and pearlite were obtained. It was found that for every steel the hardness versus amount of ferrite curves were of an exponential type, ascending steeply with decreasing amounts of ferrite. Because of the somewhat different silicon and manganese contents, the steels could not be directly compared with each other. The ferrite in all the steels had roughly the same hardness, 100–130 V.P.N., whilst the pearlite had a hardness of about 250 V.P.N., varying slightly with the cooling rate. The Brinell

1 Masing, G., "Grundlagen der allgemeinen Metallkunde." Berlin, 1950, p. 492.

2 Unckel, H. A. *Metall.*, Berlin, **5**, 1951, pp. 146–150.

hardness number, which in that range is the same as the Vickers hardness number (V.P.N.) was 98 with the 0·15% C. steel, cooled in the furnace, and 103 after cooling in air. The 0·35% C. steel gave correspondingly 170 and 187, the 0·45% C. steel 132 and 163, and the 0·6% C. steel 160 and 220.

Eutectoid Steel

Gensamer, Pearsall and Smith[3] heat treated eutectoid steel isothermally, in order to obtain varying degrees of fineness of the pearlite, and found that the logarithm of the interlamellar spacing was proportional to the strength and hardness. The present author studied the influence of varying spacing of the pearlite lamellae, obtained by different rates of cooling, on hardness, yield point and tensile strength, and found an exponential law connecting properties (e.g. hardness) with spacing of the form

$$H = Ae^{-By} + C$$

Where A, B and C* are constants for the specific material, and y is the interlamellar spacing. This formula is based on the assumption that under plastic deformation of a soft mass containing hard particles, each successive layer of the matrix adjoining an embedded particle has to carry a load equal to the sum of the loads in all previous layers, reckoned towards the particle. In other words, the stress decreases exponentially as the distance from the particle increases. This type of expression seems to fit in with the behaviour of two-phase alloys in general.

3 Gensamer, M., Pearsall, E. B., Smith, G. W. *Proc. Amer. Soc. Metals*, **28**, 1940, pp. 380–328.
Gensamer, M., Campbell Memorial Lecture, *Proc. Amer. Soc. Metals*, **38**, 1946, pp. 44.

* C represents the hardness of the soft matrix, $A + C$ the hardness of the hard phase, and B governs the steepness of the curve.

TABLE I.—1·3% CARBON STEEL

Treatment	Description of Structure	Macro-Hardness (Vickers)	Micro-Hardness of Constituents — Mean Values		Tensile Strength kg./mm.²
Spheroidized.	Spherically shaped carbides, mostly of diameter 0·0015 mm. and up to 0·03 mm.	204	Carbide Matrix	405* 187	73
Furnace-cooled.	Carbide films along the boundaries of the eutectoid whose interlamellar distance is 0·001 mm.	262	Carbide Matrix	445* 222	77
Water-quenched from 970° C.	Martensite with 0·001 × 0·01 mm. needles.	673			
Quenched and tempered at 500° C. for 1 day.	Structure hardly resolved.	331			109
Quenched and tempered at 600° C. for 5 min.	0·0015 mm. thick carbide films along former austenite grain boundaries.	458			
Quenched and tempered at 600° C. for 1 hour.	As above, with carbides mainly of 0·002 mm. diameter, although some as small as 0·00025 mm.	322			107
Quenched and tempered at 600° C. for 5 hours.	As above, but carbide particles 0·001–0·006 mm. (mainly 0·004 mm.) diameter.	301			
Quenched and tempered at 600° C. for 1 day.	As above, but carbide particles 0·003–0·006 mm. diameter with a few large agglomerations 0·008–0·08 mm.	251			78
Quenched from 970° C. into lead bath at 500° C. and held for 1 hour.	Thin carbide films along the former austenite grain boundaries. About 30% consisted of light etching areas of some 0·03 mm. diameter.	409	Light spots Dark areas	462 323	
As above, but held at 500° C. for 5 hours.	As above—matrix grainy or finely pearlitic.	395			
As above, but held at 500° C. for 1 day.	As above, with carbide films on austenite grain boundaries and crystallographic planes 0·002 mm. thick, carbide particles 0·00025 mm. diameter, fine pearlitic and light etching spots.	371	Light spots Dark areas	445 319	131
Quenched from 970° C. into lead bath at 600° C. and held for 30 min.		392	Light spots Dark areas	446 284	
As above but held at 600° C. for 4 hours.	Essentially as above, with a pearlite interlamellar distance of 0·0007–0·001 mm. and grainy carbide 0·0009–0·0095 mm.	352	Light spots Dark areas	358 272	
As above but held at 600° C. for 1 day.	As above, but with round carbide particles of 0·00025–0·0025 mm. in the matrix.	308	Light spots Dark areas	414 249	
Quenched from 970° C. into lead bath at 720° C., held for 5 min. and slowly cooled.	0·006 mm. thick carbide films along the austenite grain boundaries. Pearlite interlamellar distance 0·0012–0·0017 mm.	271			
As above, but held at 720° C. for 15 min.	As above, but pearlite interlamellar distance 0·0025 mm.	222			
As above, but held at 720° C. for 2 hours.	As above, but thickness of carbide films 0·01–0·06 mm.	226			
Quenched from 970° C. into lead bath at 850° C., held for 5 min. and slowly cooled.	As above, but thickness of carbide films 0·012 mm., and pearlite interlamellar distance 0·0015–0·003 mm.	241			
As above, but held at 850° C. for 15 min.	Essentially as above.	268			
As above, but held at 850° C. for 1 hour.	As above.	268			
Quenched from 970° C. into a lead bath at 720° C., held for 3 min. and then quenched and tempered at 600° C. for 30 min.	0·003 mm. thick carbide films along former austenite grain boundaries. Matrix grainy with most particles 0·004 mm. diameter.	325			
As above, but held at 720° C. for 10 min.	As above.	319			
As above, but held at 720° C. for 1 hour.	As above, but carbide films at grain boundaries 0·005 mm. thick.	320			
As above, but held at 720° C. for 5 hours.	As above, but film thickness increased to 0·006 mm.	315			

* Values too low. The true hardness of cementite is 700–800 V.P.N., but the particles were too small to allow accurate determination.

Hyper-eutectoid Steel containing 1.3% Carbon

In this steel, pro-eutectoid carbide is rejected on cooling slowly from the austenitizing temperature, the final structure consisting of pro-eutectoid carbide along the grain boundaries of a pearlitic matrix. Carbide may also be precipitated on certain crystallographic planes within the grains. The particle size was measured with the light microscope which, however, suffers from the disadvantage that extremely fine particles cannot be resolved. This is particularly unfortunate as the greatest change in properties is effected at these extremely fine dispersions and particle sizes. W. A. Wood[4] has used X-ray methods of particle size determination in studying the dependence of hardness on particle size, in the case of chromium steel, varying particle sizes being obtained by progressive tempering. In the present work, a blue filter was used with the light microscope since the resolution is somewhat greater with light of short wavelength. The micro-hardness tests were carried out with a Hanemann apparatus. Vickers macro-hardness measurements were made with a 30 kg.

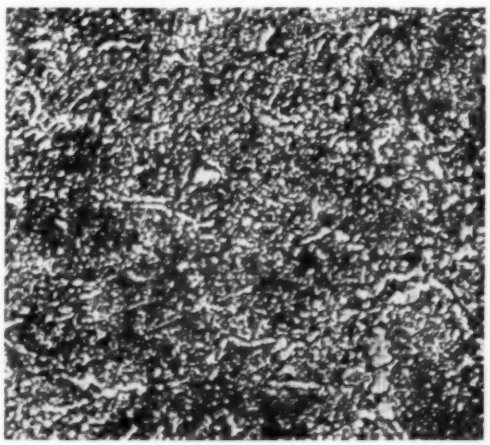


Fig. 1.—1.3% C steel—highly spheroidized state. ×800

load throughout.† Heat treatment of the specimens of size 1 × 1·5 cm. comprised different cooling rates, isothermal treatments in lead baths held at different temperatures, quenching in water or, in the case of the chromium steel, in oil.

The results obtained are detailed in Table I and some typical structures are shown in Figs. 1–5. The lowest hardness is, of course, obtained in the highly spheroidized condition, the pro-eutectoid and the eutectoid carbide occurring as more or less rounded particles in a continuous ferritic matrix (Fig. 1). Cooling in the furnace, on the other hand, leads to a coarse pearlitic structure, the pro-eutectoid carbide being present as large particles (Fig. 2). The ferrite in the pearlitic matrix is now not continuous and interconnected, but is interrupted by the hard, stiffening carbide lamellae. Accordingly, the hardness is about 25%, and the strength 6% higher than in the spheroidized state. The carbides have a hardness

† Although the micro-hardness values should agree with the Vickers macro-hardness values, since the indentations are made with the same form of diamond, the former were found to be rather high, presumably due to some systematic error. A correction factor of 1·15 was therefore applied and was based on results on single-phase structures.

4 Wood, W. A., *Phil. Mag.*, **10**, May 1930, p. 1,073, p. 185; O'Neill, H., "Hardness of Metals and its Measurement," Chapman and Hall, 1934, p.185.

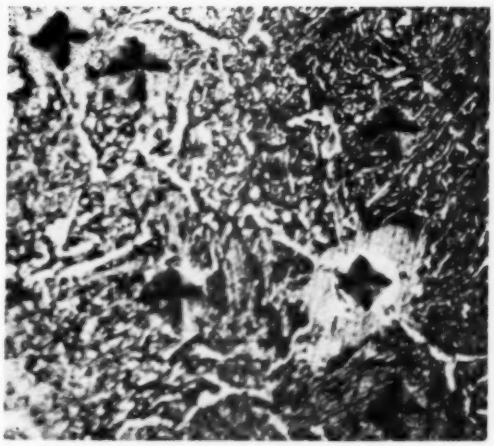


Fig. 2.—1.3% C steel—furnace cooled. Hardness indentations made by 25 g. load.† ×800

of over 500 and the ferrite of about 100, whilst the hardness of pearlite with an interlamellar spacing of 0·001 mm. is 220. Since the pearlite contains only 12·7% carbide by weight, or 13·8% by volume, the considerable stiffening effect exerted on the ferrite by the cementite is apparent. If the hardness in the spheroidized state is compared with that in the furnace-cooled condition, the effect on hardness of the form and arrangement of the carbide particles may be seen.

A very fine dispersion of carbides can be attained in two ways: either by quenching from a high temperature and tempering for different times, or by isothermal transformation. Approximately the same hardness results from tempering at 600° C. for less than one hour as from tempering at 500° C. for one day. At 600° C., the hardness falls very rapidly at first, and approaches the hardness of the furnace-cooled condition after one day. In this case, the carbide does not occur in the lamellar form, as in pearlite, but as a fine precipitate from the originally austenitic matrix. This precipitate,

† All other indentations shown in these illustrations were made at 50 g. load.

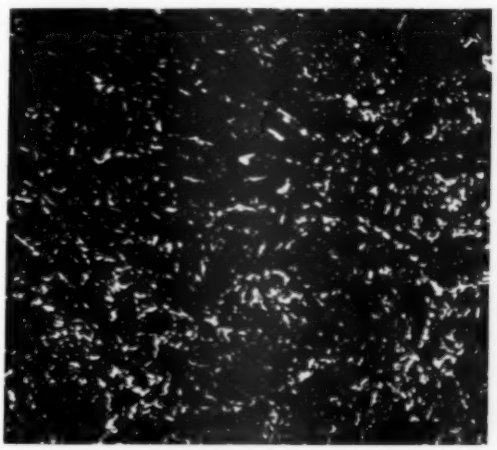


Fig. 3.—1.3% C steel—quenched from 970° C. and tempered at 600°C. for 1 hour. ×1,200

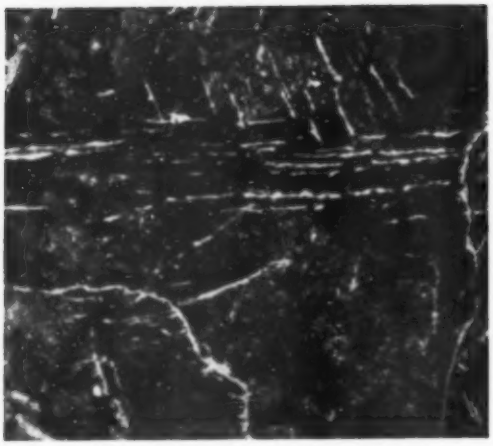


Fig. 4.—1.3% C steel—isothermally treated at 500° C. for 1 day. ×1,200

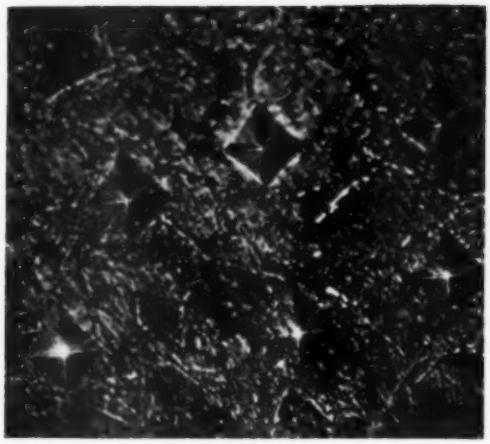


Fig. 5.—1.3% C steel—isothermally treated at 600° C. for 1 day. ×800

during the first stages of tempering, is rejected from the supersaturated martensite in a sub-microscopically fine dispersion. The particle size becomes coarser through agglomeration with prolonged tempering times, especially at higher temperatures. The structure then consists of coarse and fine particles of carbide in a substantially ferritic matrix, the finer particles having the greater effect on hardness.

TABLE II.—HIGH CHROMIUM STEEL

Treatment	Description of Structure	Macro-Hardness (Vickers)	Micro-Hardness of Constituents (Mean Values)		Tensile Strength kg./mm.²
Spheroidized.	Larger carbides, mostly about 0·007 mm. across, in a matrix containing small round carbides down to 0·0005 mm. diameter.	236	Carbide Matrix	750 221	99
Oil quenched from 1,050° C.	Primary carbides, mostly about 0·003 mm. across with small round carbides of 0·001 mm. down to 0·0001 mm. diameter in a hardly-resolvable martensitic matrix.	707	Carbide Matrix	1430 698	
Oil quenched from 1,050° C. and tempered at 500° C. for 4 hours.		749	Carbide Matrix	1860 763	
Quenched and tempered at 500° C. for 1 day.	As above.	709			
Quenched and tempered at 500° C. for 2 days.	As above—martensite with flaky appearance.	610	Carbide Matrix	985 620	
Quenched and tempered at 550° C. for 2 hours.	Essentially as above.	586			
Quenched and tempered at 600° C. for 30 min.	Larger carbides of 0·015-0·03 mm. diameter, and smaller round carbides of 0·003-0·005 mm. diameter set in a matrix containing fine particles of 0·0007 mm. diameter.	598	Carbide Matrix	1030 560	188
Quenched and tempered at 600° C. for 5 hours.	Essentially as above.	468	Carbide Matrix	720 327	
Quenched and tempered at 600° C. for 1 day.	As above, with martensite decomposed to particles 0·001 mm. diameter.	413	Carbide Matrix	630 319	120
Quenched from 1,050° C. into lead bath at 500° C. and held for 1 hour.	Large carbides of 0·015-0·03 mm. across and smaller carbides in round (0·005 mm.) and angular (0·0015 × 0·006 mm.) form.	672	Carbide Matrix	1450 766	
As above, but held at 500° C. for 4 hours.	As above. Total carbide about 60%.	685			
As above, but held at 500° C. for 1 day.	Larger carbide particles with angular contours.	685	Carbide Matrix	1210 716	
Quenched from 1,050° C. into lead bath at 600° C. and held for 20 min.	As above, with small rounded particles (0·001 mm. diameter and less) in matrix.	710	Carbide Matrix	1630 900	225
As above, but held at 600° C. for 2 hours.	Larger carbides very angular; smaller particles grown to 0·012 mm. diameter.	618			
As above, but held at 600° C. for 1 day.	Larger carbides 0·06 mm. across and angular total carbide about 70%. Matrix flaky and grainy.	375	Carbide Matrix	590 270	120
Quenched from 1,050° C. into lead bath at 700° C. and held for 1 hour.	Larger carbides 0·06 mm. across, and smaller particles 0·006-0·009 mm. and angular.	352	Carbide Matrix	638 292	
As above but held at 700° C. for 4 hours.	Essentially as above.	325			
As above, but held at 700° C. for 1 day.	As above. Very grainy matrix containing particles of 0·001 mm.	314			

* Upper values obtained by rough estimation. The carbides, especially those of the larger sizes, were very unevenly distributed and the true value is considerably lower

By isothermal treatment below the A_1 point, on the other hand, the austenite is directly decomposed to "bainite" which at the higher transformation temperatures consists of fine pearlite, and at the lower transformation temperatures of a structure not resolvable by the light microscope, but which, according to recent work with the electron microscope, is reported to consist of extremely fine pearlite. Tempering of the quenched steel at 600° C. gives the same hardness as isothermal treatment at that temperature for longer times. As with tempering, the higher temperatures for isothermal treatment result in lower hardness for the same time because of the formation of coarser carbide particles. Microscopic examination revealed spots on the isothermally treated specimens which etched in a lighter colour than the rest of the mass. As indicated by microhardness tests, these spots had a considerably higher hardness. Presumably, the decomposition does not proceed evenly, and these spots may consist of a finer precipitate or be richer in carbide. Spots of this type have been observed even after 20 hours treatment at 600° C.

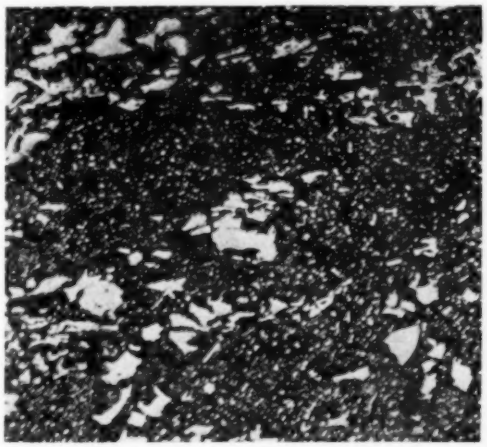


Fig. 6.—High chromium steel—highly spheroidized state. ×400

In order to study the effect of different distribution of pro-eutectoid carbide, a series of specimens was austenitized at 970° C. and then transferred to a lead bath held at 720° C. or 850° C. for different times, to allow the amount of pro-eutectoid carbide, corresponding to equilibrium, to segregate out: from these temperatures the specimens were slowly cooled, shielded by insulating brick. The small variation in the hardness values obtained does not allow conclusions to be drawn on the influence of the amount of pro-eutectoid carbide. Another series was isothermally treated at 720° C. and then quenched and tempered at 600° C. for half-an-hour. No hardness differences were found after the different times at 720° C., the values corresponding with those obtained from specimens quenched from 970° C.: the arrangement of the pro-eutectoid carbide does not, therefore, seem to affect the hardness of steel with this composition and treatment. In practice, hardening of hyper-eutectoid steels is carried out by heating to a temperature of 50–100° C. above the A_1 point, i.e., in the carbide—plus austenite range, before quenching. The carbide prevents undue grain growth of the

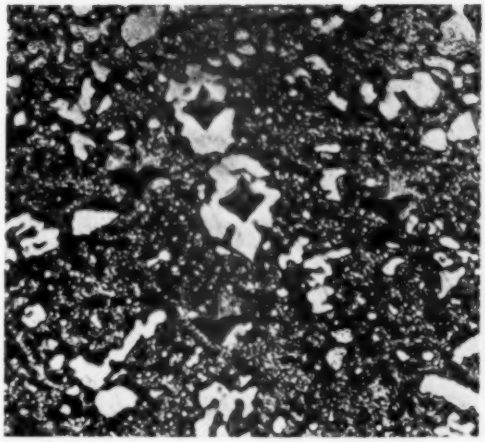


Fig. 7.—High chromium steel—quenched in oil from 1,050° C. ×800

austenite and need not be dissolved completely as it is hard in itself. The results obtained with specimens heated to 970° C. and 720° C. before quenching show that the hardness is the same whether the pro-eutectoid carbide is dissolved or not.

High Chromium Die Steel

This steel, which contains 12% Cr, 1·6% C, 0·2% V, and 0·8% Mo, has a high wear resistance due to the very hard complex carbides. It is known that two kinds of carbide occur in high chromium steels: a primary stable carbide $(Fe, Cr)_7 C_3$ formed on solidification, and another carbide $(Fe, Cr)_3C$ formed in the eutectoid transformation. The latter carbide tends to change to the stable modification at temperatures above 500° C.: the presence of molybdenum and vanadium may modify the conditions somewhat.

In the softest, spheroidized state, the hardness is somewhat higher than with the 1·3% C steel, and the structure shows a large amount of special complex carbides, arranged in streaks in the direction of hot rolling (Fig. 6). In this condition, these carbides have a micro-hardness of 860, but after quenching in oil from

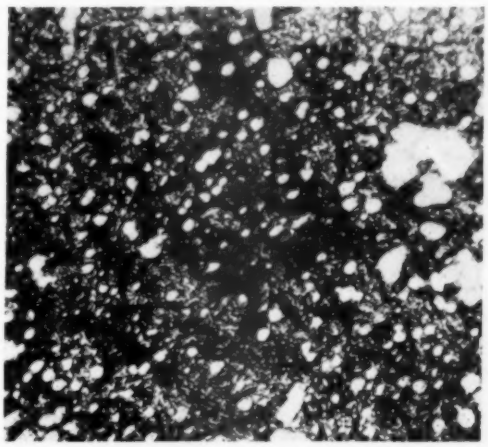


Fig. 8.—High chromium steel—quenched in oil and tempered at 600° C. for 1 hour. ×1,200

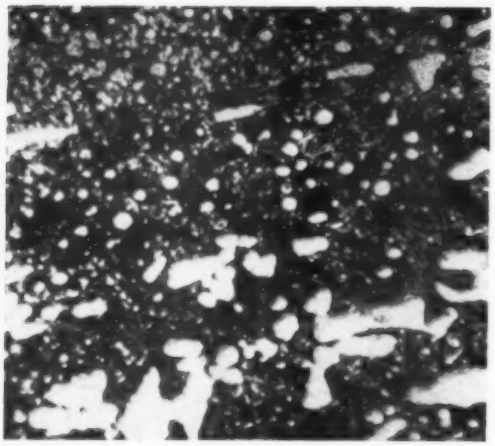


Fig. 9.—High chromium steel—isothermally treated at 600° C. for 2 hours. ×1,200

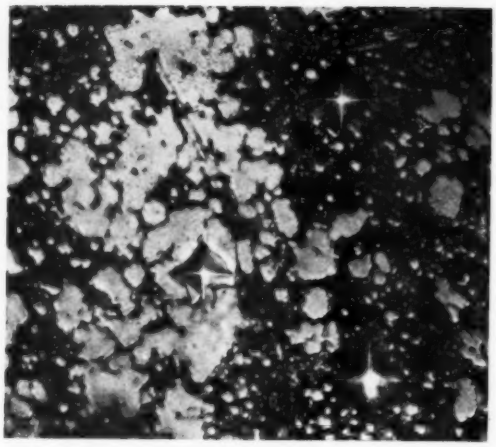


Fig. 10.—High chromium steel—isothermally treated at 700° C. for 1 day. ×800

1,050° C., the figure was found to be about twice as high (Fig. 7), and still higher after tempering at 500° C. Prolonged, tempering, especially at higher temperatures, leads again to a decrease in hardness of the carbides. The decrease in general hardness, presumably caused by the decomposition of the martensitic matrix, takes place only slowly during tempering, on account of the sluggishness of diffusion in these temper-resisting steels (Fig. 8). Even after a day at 600° C., the hardness has not fallen to that in the fully annealed state.

If the micro-hardness of the constituents is compared with the macro-hardness (V.P.N.), the micro-hardness values for the matrix, especially at the higher hardness levels, seems too high. The reason might be sought in that the matrix in the hardened or lightly tempered condition does not contain coherent carbide-free spots of sufficient size to allow evaluation of the true hardness of the matrix. The finely dispersed carbides then tend to shift the hardness to higher values. In connection with the progressive softening during tempering, it was observed that the originally sharp-edge contours of the primary carbides became more diffuse, possibly as a result of the formation of the stable carbide from the matrix.

Although the overall hardness of this chromium steel is of the same order as that of the plain 1·3% C. steel, the tensile strength after corresponding treatments is much higher.

Isothermal transformation of the austenite in lead baths results in about the same hardness as tempering after oil-quenching. At 600° C., the same hardness is reached after 20 minutes as in the oil-quenched state: prolonged time at that temperature lowers the hardness. Treatment at 700° C. results in a relatively low hardness after one hour, and it continues to decrease very slowly because of the agglomeration of the carbides. Figs. 9 and 10 show isothermally transformed structures.

In considering the manner in which the measured micro-hardness depends on structure, it may be argued that the hardness is determined predominantly by the hardness of the matrix, which consists of decomposition products of austenite. The primary carbides cannot, at least as far as the larger particles are concerned, contribute significantly to the hardness on account of their relatively small number and their relatively large distance from each other. During the decomposition of the matrix on tempering, and the change of the carbide from the unstable to the stable form, the number of carbide particles increases together with their size. The softening effect of the matrix decomposition and the accompanying release of lattice strains far outweighs any tendency to hardening. The fact that the hardness of the primary carbides decreases on tempering cannot substantially influence the matrix hardness because the carbides have still a much greater hardness than the tempered matrix.

Increased Boliden Ore Reserves

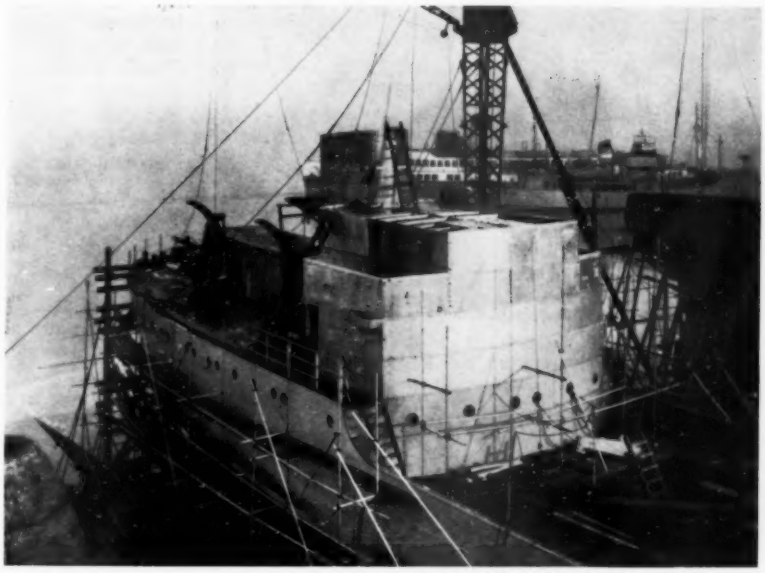
THE total ore deposits of the Boliden Mining Company, Sweden's most important producer of iron pyrites, copper, sulphur, gold, silver and arsenic, are estimated at approximately 37,000,000 tons. This figure and a report of past and present activities have just been made public in conjunction with the recent offer for sale of a parcel of 539,200 shares, 7/10ths of the majority held by Skandinaviska Banken, to the shareholders of the bank.

A total of 6,200,000 tons of ore have been mined in the original Boliden field in Northern Sweden since activities started in the '20s. It is estimated that this field, which contains only surface lodes, will be exhausted in another ten years. However, a number of new fields have been opened in the vicinity of Boliden proper (Åkulla, Renström, Långsele, Långdal) and at some distance (Kristineberg and Laisvall). The total deposits of 37,000,000 tons now available are expected to last for thirty years at a rate slightly surpassing the present rate of extraction. Moreover, extensive prospecting is now going on, and several promising new sites have been found. The company's output in 1950 was valued at Kr. 123,000,000 (£8,500,000).

The Company owns smelting works at Rönnskär on the Gulf of Bothnia, including copper works, lead works, precious metal works and arsenic works. Electrolytic copper is manufactured on an extensive scale, the value of this output amounting to 40% of the Company's sales. The copper works have an annual capacity of 29,000 tons, and the lead works 20,000 tons. In addition, gold accounts for 10% of Boliden's annual output.

Aluminium as a Shipbuilding Material

This article is an abridged version of a paper read last month before the North East Coast Institution of Engineers and Shipbuilders by Dr. E. C. B. Corlett, Naval Architect of the British Aluminium Co. Ltd., who is engaged on development work with aluminium in ships' structures. Materials and their present status, the methods of joining them, and future trends are discussed in that part presented here. In the original paper, the outline of a code of practice is sketched; a new set of standard sections is proposed, geometric properties of such a range being given, and scantling tables for deck-houses and light superstructures are put forward.



Courtesy of James Lamont and Co. Ltd., Greenock.

View of M.V. "Theron" under construction showing the superstructure which is built almost entirely of aluminium alloy.

IT is now more than half a century since the first all-aluminium craft were built, but the present large-scale marine uses of aluminium do not date back further than 1930. In the early examples, the materials used were either pure aluminium, with very high corrosion resistance but low mechanical strength, or the Duralumin type of alloy developed by Wilm in 1906 for airship and, later, aeroplane structures, and for which the reverse holds. When the alloys of magnesium with aluminium were introduced, however, it was apparent that they gave promise of wide-spread application at sea, having acceptable strength together with excellent corrosion resistance. Craft up to 70 ft. in length were constructed and their performances in service have given strong reasons to support this view.

At the outbreak of war, the structural use of aluminium was spreading slowly in shipbuilding, but hostilities, with vast requirements for aluminium alloys for air frames, removed all possibility of marine progress for some time, at any rate for non-military work. To marine development, however, this position may have proved a blessing in disguise as so voracious were the aircraft factories that world aluminium extraction, rolling and extrusion capacity proved quite inadequate and the resulting expansion finally overtook and passed the demand that engendered it, leaving substantial capacity available for other uses, even in war-time. Concurrently, the unit size of plant increased considerably and plates and bars of economic size for shipbuilding became available.

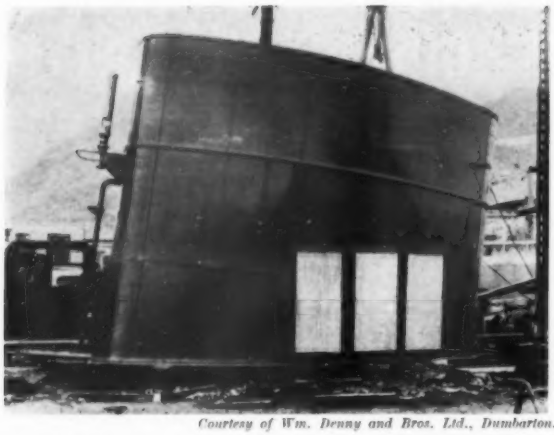
Since the war, the use of aluminium in shipbuilding has slowly but steadily gained momentum. Both mercantile and naval installations are increasing in size and number, and while it is not possible to discuss the latter, some idea of progress in the former can be gained from the details of what is, to date, the largest aluminium structure in existence, namely, the upper decks of the liner *United States*, shortly due to go into service on the transatlantic run. The weight of aluminium alloy involved is some 2,000 tons, producing a direct weight saving of 2,500 tons and an indirect saving of approximately three times this figure.

With this installation, aluminium can be said to have graduated from the incidental stage in large-scale shipbuilding and to have become fully fledged as a structural material. A stage, then, has been reached at which it is profitable to pause and review the position.

Materials

As stated earlier, those aluminium alloys containing magnesium are commonly regarded as the marine materials, together with those of the magnesium-silicide group. For structural use, a magnesium content of 3% is the practical lower limit for acceptable strength, while research and experience have given compelling metallurgical reasons for not exceeding 5½%. In, for instance, an alloy containing 7% magnesium, an inter-metallic compound may precipitate at the grain boundaries and lead to rapid corrosion of the material if stressed. To quote an example, certain Italian naval installations during the war experienced this effect which rapidly destroyed 7% magnesium rivets.

The magnesium-silicide group, i.e. those alloys containing small quantities of magnesium and silicon as alloying elements, are easily workable and extrudable metals and are commonly used for bars, but in North America they are in common shipyard use for plate, bars and rivets. Being heat-treatable, their properties are easily controlled, but this is a serious drawback if welded construction is adopted, as will be shown later.



Courtesy of Wm. Denny and Bros. Ltd., Dumbarton.

Aluminium funnel constructed of aluminium plate and section for use on the T.S.S. "Brighton."

Continental practice formerly favoured the magnesium-silicide group, for example under the name of "Anticorodal," but, in common with America, seems to be swinging rapidly to the British type of material, due largely to the impact of the introduction of practical production welding methods.

The original spate of alloys has now subsided considerably and a standard shipbuilding plate has been adopted in this country and may be adopted in a much wider field. This promising state of affairs is due, in no small measure, to the initiative of Lloyd's Register of Shipping who introduced in 1947 "Tentative Requirements for Quality and Testing of Aluminium Alloys for Shipbuilding Purposes." These requirements, the first in the world, were based on metal falling in the groups described earlier for composition, while the required minimum mechanical properties were based on those of the 5% magnesium alloy in the annealed or soft condition. Although satisfactory on paper and for small-scale production, serious economic and physical difficulties arose when large plates were contemplated in quantity production.

Plate

5% magnesium is a relatively difficult material to roll and, in order to avoid the trouble known as "crocodiling" during hot rolling, it may be necessary to cast the rolling blocks with vee ends and limit the overall dimensions. The maximum size of plate is limited and costs are relatively higher than with most of the other materials normally produced.

After much research, an alloy containing 4% magnesium and a certain amount of manganese was evolved, and this proved to be a practical and economic material. On one plant, for instance, the maximum plate size for normal production increased from 18 ft. × 6 ft. to 30 ft. × 6 ft. and this length has been exceeded considerably for special production. The mechanical properties of the alloy when hot rolled meet Lloyd's requirements with a handsome margin and the plate has been shown to be readily welded by the latest methods. This plate alloy is now designated *NP*5/6 under the British Standard general engineering specifications and is, in fact, the standard plate supplied for shipbuilding in this country. Corrosion resistance is very high and in the absence of bimetallic contacts the plate is virtually unaffected by sea-water.

The American plate materials normally used under the alloy name 61*S*-*T*6 have mechanical properties comparable with those of *NP*5/6, but these are obtained by heat treatment. There is a divergence of opinion apparent here, where riveted constructions are concerned, as the United States and Continental navies have used large quantities of heat-treated material, while the Royal Navy has insisted on non-heat-treatable alloys. If heated in a shipboard fire, the heat-treated, i.e. tempered, materials lose their properties to a much greater degree than do the magnesium-aluminium alloys and this change is irreversible in the case of the former. In view of the prevalence of small fires in action there is much to be said for the British point of view which has been reinforced forcibly by the twin American inventions of Argon Arc and Aircomatic Welding.

The magnesium-silicide materials are not suitable for welding unless subsequent heat treatment can be applied, as welds of poor efficiency and of extremely low weld-metal elongation are obtained. In the magnesium alloys, however, welds can be produced virtually equal to the parent metal in strength and elongation and this, of course, applies to *NP*5/6. It is believed that, as a result of this situation, there is considerable pressure in the United States in favour of a change to the British material in the form of an alloy designated 54*S*, which is very similar in composition to *NP*5/6.

If such a change be made and Canada follows suit, it is clear that over the English-speaking world there will be a virtually standard shipbuilding aluminium-alloy plate and it can be expected that the present Continental predilection for 5% magnesium is likely to be altered for the same reasons. If this comes about, obtaining materials for repair will be on much the same basis as for steel with none of the previous confusion of alloy types.

The plate position, then, is very satisfactory from most points of view. One desirable target for the future,

TABLE I. PERCENTAGE COMPOSITIONS (NOMINAL).

Material	Cu	Mg	Si	Fe	Mn	Cr	Zn	Al	Remarks
N5/6	—	3·9	—	—	0·8	—	—	Rem.	
N6	—	5	—	—	0·5	—	—	,,	
H10	—	0·7	1·0	—	0·4	—	—	,,	
61ST-6 (American)	0·25	1·0	0·6	—	—	·25	—	,,	
Lloyd's Limits	0·1	5·5	0·60	0·75	1·0	0·5	0·1	,,	Non-heat-treatable
	0·1	1·5	1·40	0·60	1·0	0·5	0·03	,,	Heat-treatable

TABLE II. MINIMUM MECHANICAL PROPERTIES.

Material		0·1% Proof Stress (tons/sq.in.)	Ultimate Tensile Strength (tons/sq.in.)	% Elongation on 2 in.	% Elongation on 8 in.
NP5/6	⅜ in.–½ in.	8 (15·5)	17 (20·5)*	12 (13·8)	(10·1)
	½ in.–¾ in.	8 (12·0)	17 (19·5)	12 (22·3)	(15·4)
NE6	(Up to 2 in.)	8 (8·5)	16 (17·0)	18 (25)	
	(Over 2 in.)	7 (8·0)	16 (17·0)	18 (25)	
HE10	W	7 (10·0)	12 (15·5)	18 (25)	
	WP	15 (18·0)	18 (20·0)	10 (13)	
61ST-6	Plate	15·6 (17·4)	18·7 (20·0)	10 (15)	
	Bars	15·6 (17·4)	16·9 (20·0)	10 (15)	
Lloyds		8	17		10

* Typical figures are given in brackets.

however, would be the production of 8-ft.-wide plate. A 6 ft. maximum width complicates deck-house construction, being less than normal deck height. The capital expenditure involved in laying down plant, however, would be very large in relation to present demand and this should be appreciated by the shipowning and shipbuilding industries.

Bars

Bars, however, do not condense virtues into one material to anything like the same extent. The extrusion process does not, in general, break down grain size as much as does rolling and unless, in the magnesium group, the magnesium is taken to the upper limit and the subsidiary constituents substantially increased, it is difficult to achieve the Lloyd's figures for strength. In practice, it is necessary in most cases to stretch the extrusion to produce cold work, and thus to raise the proof stress. This, in itself, is not always desirable as it may result in differing proof stresses for the tensile and compressive fibres of the member in bending and thus may affect the position of the neutral axis when a beam is heavily loaded.

The magnesium-silicide group is easily produced, the rate of extrusion at the same pressure being three to four times that of, say, *NE*6 (the Al-5% Mg alloy), and has excellent properties. The proof stress can be varied within wide limits by varying the heat treatment, although it must be borne in mind that, of course, higher proof stress involves lower elongation. Bars of this composition are rather less easily worked than those in the magnesium group, and where pronounced joggling or bevelling is required, the latter should be specified. The alloy known as *HE*10-*WP* is widely used for beams, stiffeners, frames, etc. in normal riveted construction, and is a very satisfactory material for the purpose; In America, the alloy 61*S*-*T*6 is closely similar in composition and properties to *H*10-*WP*, the chief difference being the addition of a small amount of copper.

Again, welding is threatening to alter the whole position and it is obvious that a new solution will have to be found when production aluminium welding is introduced in British shipyards. From design considerations, it is desirable that the mechanical properties of sectional members be certainly not less than those of their associated plating, and, because the neutral axis of the plating/stiffener combination is always nearer the plate than the extreme fibre of the stiffener, any increased mechanical properties in the stiffener can be used with profit. The aim, then, is a weldable, non-heat-treatable extrusion alloy with both minimum proof stress and ultimate tensile strength, fully annealed, say 20% above those required by Lloyd's. This, it can be said, is a formidable metallurgical problem. Three possibilities seem attractive, namely :—

(1) The use of a material such as *NP*5/6 combined with the *rolling* of sections, thereby applying non-discriminatory cold work.

(2) New alloy compositions which will give higher strength in the soft condition.

(3) The fabrication of sections from *NP*5/6 plate on a press brake. Although of limited application, this method—especially if material with a minimum proof stress of, say, 11-12 tons/sq. in. were used—would offer valuable economies. Annealing in the region of a weld, being close to the neutral axis, would have little effect on a plate/stiffener combination. Corrugated bulkheads and flanged floors are obvious applications of this method.

Courtesy of Yarrow and Co. Ltd., Glasgow.

P.S. "Yamuna," one of a series of shallow-draught paddle steamers built for the Oudh-Tirhut Railway Company of India for use on the River Ganges. The superstructures were almost entirely constructed of aluminium plate and section.

None of these suggestions may be practicable, but if one, or all, were successful, they would offer the possibility of improved all-welded homogeneous aluminium structures. As a further personal opinion, the Author feels that this problem is likely to become urgent in the next few years. and the opinion of shipbuilders on the third possibility listed would prove valuable as guidance.

Rivet Materials and their Use

Rivet materials are, to some extent, covered by the earlier remarks and both the *N*6 and *H*10 type alloys are widely used, the former in this country and the latter in America.

*N*6 is a work-hardening alloy and, consequently, either hot or cold, the rivet must be closed with as few and as heavy blows as possible. This places a limitation on pneumatic riveting, which cannot be said to be economical, although quite feasible, above $\frac{1}{2}$ in. diameter for cold driving and $\frac{3}{4}$ in. for hot driving. Research on the work required to drive different points has raised the upper limit about 30% above these figures, but as many of the large rivets as is possible should be closed hydraulically.

*H*10 does not work harden to the same extent as *N*6, but has a higher proof stress in the fully aged condition—thus requiring more work to produce a given amount of plastic deformation. However, if driven immediately after quenching, the alloy has much the same driveability and strength as *N*6. The disadvantage is that the rivet ages naturally after quenching, but in American shipyard practice this is overcome by keeping such rivets in ice-cream deep-freeze cabinets and issuing them in paper and aluminium foil bags which retain the cold and restrain ageing for an hour or so. Typical production figures achieved by this method on a recent large installation in the U.S.A. are :—

Diameter and Type.—$\frac{1}{2}$ in. countersunk point, chipped smooth and peened. 61*S*-*T*4 material.

Team.—One riveter, one holder-up with pneumatic dolly, and one fetch and carry.

Courtesy of Viking Marine Ltd.

One of a series of 24 ft. standard lifeboats constructed of 12 s.w.g. aluminium alloy sheet and section.

Tool.—One No. 20 hammer with interchangeable chipping head and riveting head.

Quench Temperature for Rivets.—1,040° F.

Freeze Temperature.— — 10° F.

Rate.—1,500 per day per team, approximately 6 per minute of driving time horizontally and 4 per minute vertically.

In the liner *United States*, some 1,200,000 aluminium rivets were used and this method was adopted throughout.

The hot driving of *N*6 rivets requires fairly accurate, but simple, temperature control, and this can be achieved by a suitable electric oven. The shear strength produced is about 12 tons/sq. in. in single shear, comparing with 13 tons/sq. in. for cold-driven rivets. These are typical figures but having two shear strengths for an *N*6 rivet, depending upon whether it has been cold or hot driven, need not complicate drawing-office work.

Where drilling is done on site, a nominal diameter drill, if passed through the plate, will leave sufficient clearance to accommodate the normal tolerance on a cold aluminium rivet. A hot rivet, however, requires approximately the same expansion allowance as does a hot steel rivet of the same diameter. If the clearance normally recommended is used, the driven rivet has an area in excess of that of the cold-driven rivet. The product (shear stress × driven area) is then nearly constant for diameters from $\frac{1}{2}$ in.–$\frac{7}{8}$ in. either cold or hot driven, and hence, a simple rule emerges :—

> The ultimate shear load on an *N*6 rivet, whether hot or cold, may be taken as the area based on the nominal diameter multiplied by, say, 12 tons/sq. in. standard design shear stress. This, of course, only applies when the above procedure for clearances is adopted.

In stressed aluminium structures, much more drilling on site will be required because of the smaller clearances, but in the opinion of the Author, the disadvantages of this are largely compensated by the greater ease of drilling and the possibility of prefabricating more extensively than is common with steel. Aluminium riveting need not be more expensive in labour than steel riveting if techniques such as those suggested above are used, and if riveting at the top end of the diameter range for the methods and tools available is avoided.

Welding

The opinion has been expressed by an eminent shipbuilder that, cost apart, aluminium ship structures will never be really attractive until shipyard production welding of the components is possible. This view is clearly gaining force as good riveters (and, to face facts, they have to be good with large-diameter aluminium rivets) become more scarce, as drawing-office practice and yard layout gravitate towards welded steel construction and as the cost of steel increases.

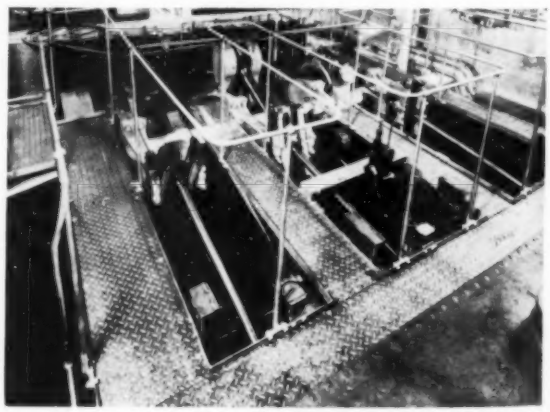
To illustrate, the weight of riveted aluminium required to produce the equivalent of a welded steel structure is of the order of 40-43% of the steel weight. The saving in cost of aluminium obtained by welding instead of riveting would be very nearly half the entire first cost of the steel. To this must be added the factor that in many cases the latest aluminium welding techniques are appreciably cheaper than riveting, per foot of join.

In chronological order, the processes made available are :—

(1) Gas welding in its various forms.
(2) Metallic arc welding.
(3) Argon arc welding.
(4) Self-adjusting arc or Aircomatic welding.
(5) Controlled arc welding (machine head Aircomatic welding).

This apparently formidable list is reduced by the elimination of (1) for shipyard use, the limiting of (2) to non-stressed welds and by the availability of (4) and (5). It is probable that (3), (4) and (5) are the only processes at present of real interest to the shipbuilder.

Metallic arc welding is simple and can be used where strength is not important (e.g. caulking boundary bars on deck-houses); but the welds are of poor quality, being porous and relatively weak. The oxide of aluminium is heavier than the parent metal, as are many of the suitable fluxes—the reverse of the case with steel—and consequently oxide and flux entrapment are an ever-present danger. Most fluxes are corrosive to aluminium, needing great care in final cleaning. Wire brushing of the surface to be welded removes the initial oxide film, but oxidation during the welding period is rapid and no weld is likely to be free from inclusions and porosity.



Courtesy of Yarrow and Co. Ltd., Glasgow.

View of the engine room of the shallow-draught paddle steamer "Sarayu" in which P-G-P treadplate was used for gangways.

Argon Arc Process

The solution has been produced in the argon arc process and its later developments, where no flux is used and the arc is struck in an inert atmosphere.

The normal argon arc process is by now in wide-spread use and produces first-class welds in the aluminium/magnesium alloys in the downhand position. Overhead welding has been difficult hitherto, but recent developments promise to alleviate this difficulty. In this process A.C. is applied to a tungsten electrode round which gas is passed to shield the arc from atmospheric oxygen. The filler wire is fed into the weld pool by hand from the side. This is a very satisfactory welding process under good conditions and in the hands of a good operator, the advantages being :—

(*a*) High-quality welds.
(*b*) Fairly high speed.
(*c*) No flux to entrap.
(*d*) Suitability for machine welding.

The disadvantages are :—

(*a*) A relatively complicated electric set.
(*b*) Awkwardness in some positions due to the fairly large nozzle and the need to feed in the filler rod from the side.
(*c*) The necessity to use two hands.
(*d*) Only moderate penetration, due to the polarity of the arc.
(*e*) The waste of electric energy, due to the necessity to water cool the tungsten electrode.
(*f*) The risk that tungsten contamination may result if the work is touched by the electrode.

Several of the above difficulties can be surmounted by suitable apparatus and skill, and indeed, the difficulties formerly met in overhead welding, and in welding in draughts, have not been mentioned for this reason.

To sum up, argon arc welding is a good useful process and, if deficient in some respects for major shipyard use, is eminently suitable for shop work and for production runs in its mechanized form.

Self-Adjusting Arc Process

Aircomatic or self-adjusting arc welding, also developed in the U.S.A., avoids many, although not all, of the above difficulties. Briefly, the arc is again shielded by argon or helium, but the filler rod replaces the tungsten electrode and is fed mechanically down the gun. Reverse polarity D.C. is used in conjunction with very high current densities. The advantages of the method are :—

(*a*) High-quality welds.
(*b*) Higher speed than argon arc welding.
(*c*) No flux to entrap.
(*d*) Suitability for machine welding.
(*e*) One-handed operation.
(*f*) Easy and good overhead and vertical welding.
(*g*) Much lower operator, gas and electric costs than argon arc welding.
(*h*) No cooling, all the heat going into the weld.
(*i*) Very good penetration.

The disadvantages are :—

(*a*) The high penetration limits the material thickness to a minimum of about $\frac{3}{16}$ in.
(*b*) The high surface area per unit volume of the weld wire necessitates very careful cleaning and the removal of oxide film from the wire, in order to avoid weld porosity due to dissociation of water in the hydroxides, with oxide and hydrogen inclusions as a result.

Courtesy of Smiths' Dock Co. Ltd.

Whalecatcher "Southern Foster," one of a series of vessels using aluminium alloys extensively in the superstructures and thereby reducing top weight by 10 tons.

(*c*) The previous remarks about welding in draughts apply, to a rather lesser extent but with probably the same remedy as with argon arc welding.

To sum up, Aircomatic welding is a very efficient production process, and is in wide-spread use in American shipyards. Welding is cheap and simple, even compared with coated electrode work. There seems little doubt that it, or a variant, will become the standard method for joining members in constructional aluminium work.

Material for Welding

The introduction of aluminium welding in shipyards is bound to influence the materials used and, as shown earlier, has done so in the U.S.A. Heat-treatable material is not very suitable for welding, and perhaps the worst feature is the very low resultant weld-metal elongation. In addition, the tensile properties are poor, although if the welded assembly can be heat-treated, excellent properties can be obtained ; this, of course, is impracticable on any ship structures. The British plate material *NP*5/6 is, on the other hand, very suitable for welding by the inert-gas methods, and it is a fortunate fact that for this material the best shielding gas is argon. This circumstance is quite fortuitous, but, nevertheless, it is valuable, as helium is not available in this country.

The welding of bars calls for the aluminium/magnesium materials, as the weld properties of *HE*10-*NP*5/6 joints seem likely to be very poor.

The careful siting of welds near the neutral axis of plate/stiffener combinations and in built-up girders might help but, at best, such methods are only palliatives. The most obvious solution would be to use rolled *NE*5/6 sections or flanged *NP*5/6 sections and *NP*5/6 plate with welding wire of a similar composition. Such a combination should offer very satisfactory strength, ductility and soundness of weld, and for general shipyard use some such standard practice must be established within the next few years.

Joint Preparation

The methods normally used for joint preparation are straightforward. For thin material up to and including say, $\frac{1}{4}$ in. and perhaps $\frac{3}{8}$ in., it is not necessary to vee the

Courtesy of A. McInnes Gardner and Partners and Fleco Plywood Industries Ltd.

View showing the interior of the S.S. "Himalaya" with balustrades and panelling executed in aluminium alloy.

butts in any way. A backing bar is desirable on the thinner materials and this should be slightly grooved. The bar may be of copper or stainless steel. The only danger in this method of welding is the entrapment of air in the crack between the plates which may produce oxide inclusions. This can be avoided by a satisfactory technique on the part of the operator. For very thick plates of the order of 1 in., double-vee butt preparation is required, while single-vee butt for the range between $\frac{3}{8}$ in. and $\frac{3}{4}$ in. thickness is usually regarded as satisfactory. The distortion of welded assemblies must be taken into account, of course, but although the co-efficient of thermal expansion of aluminium is twice as high as that of steel, the actual temperatures in the weld metal and the surrounding structure are very much below those in the corresponding steel joint. It is reasonable to assume that the same order of contraction allowance and the same type of sequence as is used in steel welding can be used on a similar assembly in aluminium.

Courtesy of Grimston Astor, Ltd., Bideford.

60 ft. aluminium survey launch "Ain-Al-Bahr."

Design

In general, it is a truism that careful detail design repays effort, but this is especially pertinent with aluminium. A rather more complex and efficient structure may be cheaper when completed by virtue of a saving in the relatively expensive material, while some of the advantages of the metal, such as high corrosion resistance, reduced maintenance and so on may not be realised at all unless the details of installation are carefully attended to.

Again, a careful design study should indicate the optimum extent of an aluminium installation. Incorporating aluminium can only be justified if the resulting vessel is a more attractive economic and technical proposition and it is not immediately obvious in some cases how best this can be achieved. A case in point is that of the liner *United States*. The use of a smaller quantity of light alloy in this vessel would have produced some of the technical advantages actually obtained but a less favourable overall economic picture. The ship, as built, is smaller than would have been the case with all-steel construction and it can be shown that the extra cost of the structural material is more than offset by the reduction in first cost of the smaller ship and machinery. No expansion joints are used in the 500-ft. long superstructure and the resulting light scantlings allowed a new approach to the whole design problem. Indeed, it is doubtful whether the ship could have been built in its present form without aluminium, having a rigid beam limitation and three-compartment flooding and damaged stability requirements.

Conclusion

It is apparent that aluminium has emerged from the morass of speculation and multitudinous specifications to become a useful shipbuilding material whose biggest disadvantage is a non-technical one—even, one might say, a political one. The necessity to buy the majority of our ingot from hard-currency countries has been responsible for a considerable rise in the cost of the metal.

It requires approximately 5–6 times as much energy to extract one ton of aluminium from ore as it does to extract one ton of iron from its ore. This energy must be paid for and at the moment this country is in the unfortunate position of paying for it in dollars. The building of extraction plant in the sterling area must be rated as one of the most important objectives in sight.

A further cause for concern is our present lag behind the Americans in the development of aluminium welding equipment. Both the argon arc and Aircomatic sets were in very large-scale use in transatlantic industry before the first experimental equipment was produced in Britain. This is an unnecessary and damaging state of affairs. Surely the country that invented stud welding, that built the first all-welded ship and that builds half the world's tonnage cannot be content to depend on others for the basic design of its tools.

Finally, if during the next two decades the rate of progress in aluminium shipbuilding be as rapid and encouraging as it has been since 1930, then some future author will have an interesting story indeed to unfold.

We are indebted to the British Aluminium Co., Ltd., for the loan of photographs used to illustrate this article, and to the firms concerned for permission to reproduce them.

A Contribution on the Metallic Mould Blowing Reaction

By Kondic, B.Sc., Ph.D., G. Martin, B.Sc. and K. Bromage, B.Sc.
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The results of a study of the conditions under which a chemical reaction at the metal-mould interface may give rise to "blowing" at the surface of a chill casting show that the reaction, which is essentially one of oxidation of the carbon in the mould material, can be treated quantitatively with a good approximation by using the thermodynamic data of substances involved in the reaction. By providing at the interface metals of comparatively higher affinity for oxygen than that of carbon, the reaction can be reduced and the "blowing" completely eliminated.

THE nature of the metal mould surface reaction which gives rise to blowing of the surface of a casting has been studied by numerous workers, the outstanding contribution having been made by Bailey.[1] The present interpretation of this phenomenon is largely based on his work and can briefly be stated as follows. During the pouring of molten metal into a ferrous metallic mould, the surface of the mould may reach a temperature at which the carbon of the mould reacts with any oxygen present to give rise to carbon monoxide or carbon dioxide. If the casting has already formed a solid crust at the time this reaction is taking place, the gas formed "blows" into the casting surface, forming a hole or a number of holes of differing sizes, thus leaving a honeycombed, porous surface which seriously impairs the quality of the cast product. Consequently, if there is no carbon present in the mould material, there can be no blowing, a fact well proven in industrial practice, for example, by using copper-faced water-cooled moulds in ingot manufacture. Furthermore, by excluding the oxygen, or by providing an element which will, in preference to carbon, react with oxygen, the reaction may be reduced or completely stopped.

In addition to the mould reaction "blowing" caused by carbon, the mould may blow through a number of other causes, e.g., the presence of moisture, or cracks, or suitable corrosion products at the mould surface. As these factors can be adequately controlled in normal casting practice, no further attention is given to them in this contribution.

The object of the experimental work described here was that of testing the applicability of the available thermodynamic data, of those substances which are believed to play a part in the blowing reaction, to the understanding of the phenomena involved, as well as towards the solution of the surface blowing problem in industrial casting practice.

Experimental Work and Results

The apparatus used was of a very simple type, as shown in Fig. 1. A carbon mould contains a number of holes, which are closed by small discs made in alloys whose sensitivity to the blowing reaction is to be studied. The molten alloy is poured through a tundish centrally located over the mould, so that the metal stream impinges directly on the metal discs during pouring. The discs are then examined visually and, when necessary, microscopically. There is no difficulty in recognising a genuine blow-hole, such as is shown in Fig. 2.

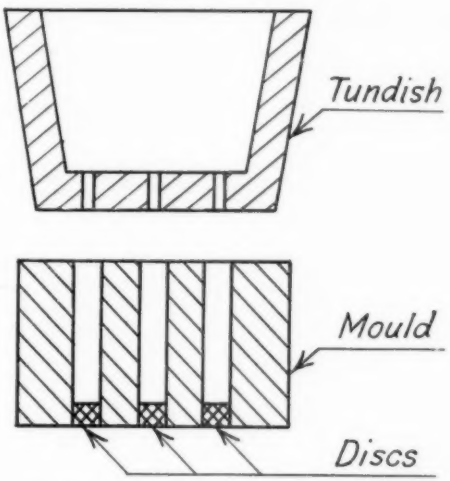


Fig. 1.—Casting assembly for testing blowing-sensitivity of discs.

The variables studied include the following: (*a*) the constitution of the disc; (*b*) the constitution of the alloy poured; and (*c*) the pouring and mould temperatures.

(*a*) As indicated already, discs made in non-ferrous alloys do not blow, but the ferrous alloys used—Armco iron, mild or high carbon steel (annealed or quenched), malleable or grey iron—all blow to a greater or lesser extent. In general, the more an alloy of this type contains combined or dissolved carbon (Fe_3C or carbon in solution in α or γ iron), the more it blows: discs made in pure graphite, for example, do not blow. Bailey's findings in this respect are thus confirmed.

Besides those other factors already mentioned, it was found that the condition of the disc surface plays an important part in the "blowing" reaction. The extent of "blowing" is increased by a preliminary oxidation of the disc, and it is reduced by coating the disc with either neutral or "active" coatings. Graphite and soot are good examples of the former, and silicone and aluminium paints of the latter type of coating. In order to magnify the blowing effects, in most of the subsequent experiments, an oxidised disc was used unless otherwise stated.

(*b*) It is a well established fact that certain alloys are

[1] Bailey, G. L., *J. Inst. Metals*, 1932, **49**, 203.

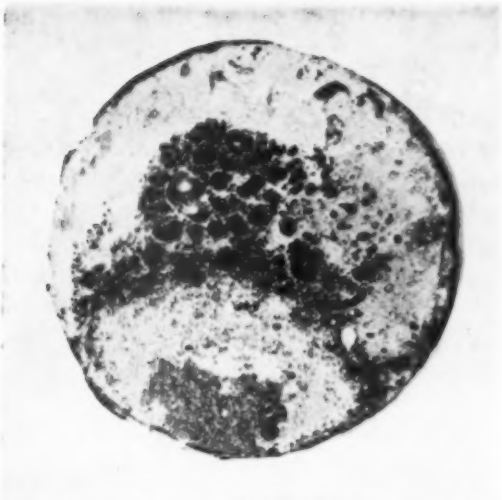


Fig. 2.—Typical " blown " surface of a disc as used in this work.

more prone to the blowing defect than others. Tin-phosphor- or leaded-bronzes and certain nickel silvers are good examples of blowing-sensitive copper-base alloys, as are brasses and aluminium bronzes of the non-sensitive types: the tests carried out in this work confirm this general conclusion. Cast iron, steel and light alloys have been found to be largely blowing insensitive, but the casting conditions may alter their behaviour to a great extent. This point is further enlarged upon later in the discussion.

With blowing-insensitive alloys, the blowing tendency was found to be dependent on the concentration of solute atoms. For example, with 0·2% (atomic) of aluminium in copper, the grey-iron discs blow only with a pouring temperature above 1,250° C. To obtain a similar effect with silicon, it is necessary to increase its concentration to 2% (atomic). On the other hand, even with 5% (atomic) of chromium, discs blew above 1,100° C.

The strongest inhibitor of the blowing reaction amongst the metals studied is found to be aluminium. It was, therefore, interesting to add this element to the disc instead of to the alloy poured. The results obtained show that it is not possible to stop blowing of pure copper at pouring temperatures around 1,250° C., even with 4·0% (atomic) of aluminium added as an alloying element to grey iron. The extent of blowing is, however, largely reduced in comparison with the unalloyed grey iron, and unoxidised discs show only a faint sign of blowing.

(*c*) In general, an increase in the pouring temperature of an alloy, or in the temperature of the disc, increases the extent of blowing of the casting. Only a few experiments were made to determine the surface temperature of the disc during pouring: surface temperatures of the order of 750–850° C. were obtained, but the technique used was not very accurate.

Discussion of the Results

It is clear from Bailey's work, and this is confirmed in the present experiments, that the " blowing " reaction is one of oxidation of carbon. No blowing is normally obtained if carbon is completely absent in the constitution of the disc, or is soluble in the liquid alloy which is being cast, or if an element is present at the mould surface whose affinity for oxygen is very much greater than that of carbon. The experiments also show that the reactive carbon is essentially that dissolved in α- or γ-iron, or that in the combined form, Fe_3C. As the blowing reaction is very slow below 700° C., in the majority of cases it can be taken that carbon dissolved in γ-iron, or present as Fe_3C, is largely responsible for the blowing reaction.

It was on the basis of the above interpretation of the nature of the blowing reaction that the experimental variables of this work were selected. Certain thermodynamic aspects of the oxidation of carbon, and of elements in general, are well established, and it is of interest to apply a similar treatment to the blowing reaction. For, if this reaction can be analysed thermodynamically, progress will have been made towards controlling the occurrence of such defects in many industrial castings. The preliminary results obtained, as is shown below, amply justify the above approach.

In the general case, the tendency of a chemical reaction is expressed by the relation:

$$\triangle F_{T,P} = \triangle F^{\circ}_{T} + RT\ln\frac{a^{l}_{L}\times a^{m}_{M}\times}{a^{a}_{A}\times a^{b}_{B}\times} \quad \ldots\ldots\ldots\ldots(1)$$

Where $\triangle F_{T,P}$ is the change of the free energy of reaction when substances are present at arbitrary activities, a_L, a_M etc., and $\triangle F^{\circ}_{T}$ is the corresponding (or standard) free energy change when the substances are present in their standard state. In order to apply this equation to the present problem, it is advantageous first to examine the change of the standard free energy $\triangle F^{\circ}$ with temperature, for oxidation gas reactions of elements of the type:

$$M_{(solid)} + O_2 \rightleftharpoons MO_{2(solid)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Richardson[2] and other workers have shown that the $\triangle F^{\circ}/T$ graph, which can be plotted from the available thermodynamic data for reactions of the above type, is

2 Richardson, F. D., and Jeffes, J. H. E., *J. Iron and Steel Inst.*, 1949, **163**, 397.

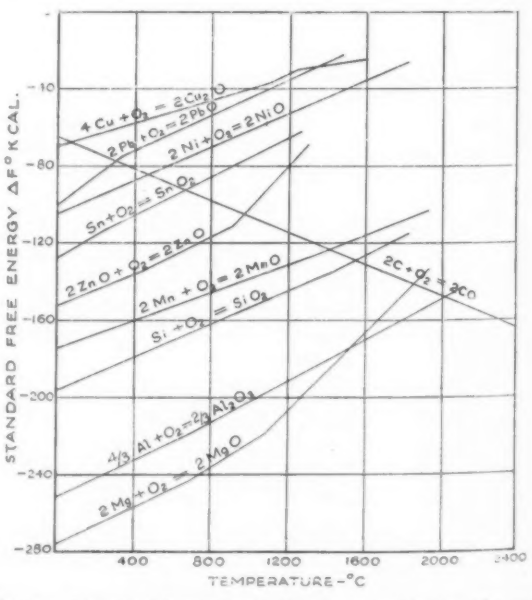


Fig. 3.—Standard free energy change of oxidation of some elements taking part in the blowing reaction.

a good method of surveying quickly the relative stability of oxides in their standard state, i.e., unit molar concentrations for solids or liquids, and 1 atmosphere pressure for gaseous substances. Such a graph is shown in Fig. 3.

In general, the larger the change of the free energy of formation of an oxide from its components in the standard state, the more stable is such an oxide. It is clear from the graph that under these conditions a number of elements are available which are capable of preventing carbon from reacting at the mould surface with any oxygen present: these include chromium, silicon, aluminium and manganese. On the other hand, alloys based on copper with nickel, tin, zinc and lead will show a tendency to blow. The further the free energy line of an element is removed, in the negative direction, from the corresponding line for carbon the more powerful is that element likely to be in preventing the blowing reaction. This is confirmed experimentally in the present work as only very small quantities of aluminium are necessary in the molten alloy to prevent blowing from the discs, whilst at the same temperature, larger amounts of silicon and still larger amounts of chromium are needed. The effect of temperature on the stability of oxides is clearly shown on the graph.

However, while the graph in Fig. 3 is a good guide for estimating the tendency of a reaction, the free energy change $\triangle F_{T,P}$ has to be obtained for an application to the present problem. In order to do this, it is necessary to substitute the values of activities of substances in the blowing reaction, under the conditions of the experiment. The procedure to be adopted will be exemplified for the case of silicon bronzes: an analogous procedure may be used with other alloys. The blowing reaction in this case is:

$$Si_{(\text{in liquid copper})} + 2\,CO_{(\text{gas})} \rightleftarrows 2\,C_{(\text{in } \gamma \text{ iron})} + SiO_{2(\text{solid})} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

It is necessary, therefore, to substitute the values of activities of dissolved silicon and carbon in liquid copper and γ-iron, respectively, into equation (1), while the changes in the activities of CO and SiO_2 need not be considered in this case, and the free energies can be taken to be equal to those in their standard state. As a first approximation, it can be assumed that the activities of silicon and carbon are proportional to their molar concentrations. The overall change in the free energy can then be directly calculated from the equation:

$$\triangle F_{T,P} = \triangle F^{\circ}_{T} + RT\ln \frac{(C)^2}{(Si)} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

The standard free energy change, as shown in Fig. 3, is increased to the extent of the product $2RT\ln(C)$, and decreased by $RT\ln(Si)$. The former factor implies that $\triangle F$ is greater than $\triangle F^{\circ}$ and the possibility of carbon monoxide being reduced by silicon is lessened, while the latter factor leads to an exactly opposite result. In general, therefore, the blowing reaction is increased by lowering the activity of the dissolved carbon (i.e. reducing its concentration), and is reduced by adding to the alloy poured larger quantities of an element whose free energy of formation is more negative than that of carbon. The more negative the free energy of formation of the oxide of this element, the less the concentration (i.e., the activity) of added element need be. It can readily be shown from equation (4) that the relative magnitude of the standard free energies of formation of the oxides is more important in selecting a suitable reducing agent than if this were done by small variations in its concentrations.

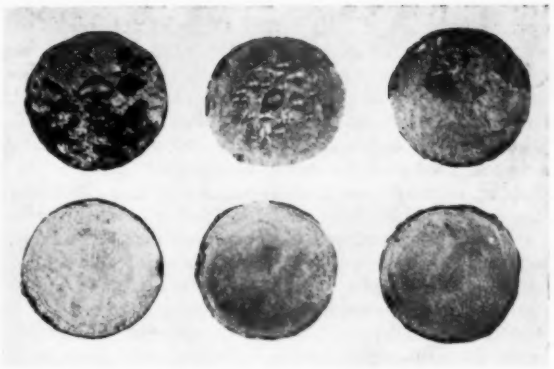


Fig. 4.—The effect of increasing pouring temperature on the blowing of copper containing 2% silicon, using oxidised grey iron discs. Temperatures: (top row—left to right) 1,300° C., 1,265° C., 1,225° C.; (bottom row—left to right) 1,185° C., 1,165° C., 1,140° C.

For more exact numerical calculations, it is necessary to use the true values of activities of reactants and products of the reaction,[2] but as has already been emphasised above, the relative differences in the standard free energies can be used as a guide for the tendency of a reaction, and the extent to which comparatively small changes of activity values modify this tendency can be ignored in an approximate estimation.

The Mechanism of the Blowing Reaction

On the basis of the experimental data available, and with the support of the theoretical analyses outlined above, the following mechanism of the blowing reaction can be put forward.

During pouring of molten metal into a ferrous mould, the mould surface may reach a temperature at which the speed of the reaction

$$2\,C_{(\text{dissolved in } \gamma \text{ iron})} + O_{2(\text{gas or oxide})} \rightleftarrows 2\,CO_{(\text{gas})}$$

is fast enough to produce a large volume of carbon monoxide which cannot escape through the pasty or just solid crust of the casting, and a "blowhole" is, therefore, formed. The speed of this reaction increases with the attained mould surface temperature, which is higher the higher the initial mould temperature and the higher the pouring temperature of the metal. The second factor determining the extent of blowing is the rate of availability of carbon. Carbon is transferred to the locality of reaction by diffusion: one might expect, therefore, that γ-iron would blow more than α-iron, both on account of higher temperatures and availability of carbon. The third factor is the availability of oxygen. Oxidised mould surfaces or molten metal streams lead to a greater extent of blowing, purely as a result of oxygen mass effect. On the other hand, the available oxygen can be "bound" with another metal, whose reactivity with oxygen is greater than that of carbon. These metals can be added to the alloy which is being cast, or to the mould. Clearly, their effectiveness in stopping the blowing reaction depends on their availability at the mould surface during pouring. This is the main reason why mould dressings containing aluminium, silicon or

silicones are most effective, and the addition of these elements to the molten alloy is the next best step in stopping the blowing reaction. In this latter case the active metals diffuse relatively rapidly through the liquid metal, but they can do so only very slowly when alloyed in the mould itself. Accordingly, as shown by the experiments, large quantities of aluminium have to be added to a grey iron mould in order to reduce its sensitivity to blowing. The effectiveness of each particular metal in stopping or minimising the blowing reaction depends on the stability of its oxide relative to that of carbon at the corresponding temperatures and concentrations, as shown in Fig. 3.

The occurrence of the blowing defect in many industrial castings can readily be explained in the light of the above interpretation of the blowing reaction. The factors which favour blowing are: (*a*) high mould or pouring temperatures; (*b*) the presence of oxides of metals which can be reduced by carbon; and (*c*) the absence of mould dressing, whether this is used as a heat insulator or otherwise. The tendency to blowing is on the other hand reduced by (*a*) insulating the mould surface, thus preventing a high temperature rise, or a contact between carbon and oxygen or oxides; and (*b*) application of "active" mould dressings which "bind" the oxygen, by formation of solid instead of gaseous oxide products.

The blowing defect is mainly obtained with ferrous moulds, which almost always contain some carbon in solution, and, therefore, in its most reactive condition from the point of view of the blowing reaction. On the other hand, blown surfaces of castings can be obtained with practically all alloys cast, whether ferrous or non-ferrous. The reason why ferrous castings are seldom blown is due to the solubility of carbon in the poured alloy itself. The blowing of non-ferrous castings is, however, mainly controlled by the temperature and the composition of the alloy, and the relative time displacement of the blowing reaction to that of the progress of solidification. If the reaction takes place prior to the formation of the solid crust, the gas formed will escape through the molten alloy. If, on the other hand, the reaction is at its highest speed during the formation of the solid crust of the casting, blown surfaces will result.

Conclusions

The blowing reaction which is characteristic of solid ferrous moulds and which is frequently met in the manufacture of shaped castings as well as of ingots, is subject to chemical laws, like any other chemical reaction. For a complete quantitative treatment of the problem a more rigorous thermodynamic analysis as well as certain thermodynamic information, which is still not fully available, are required. But a qualitative and approximate analysis of the cause of blowing can be made which gives satisfactory agreement for most practical applications.

Vertical Bell-Type Furnaces for Steel Works

NEW equipment installed at the Brierley Hill works of Richard Thomas and Baldwins, Ltd., includes six vertical cylindrical bell-furnaces supplied by The General Electric Co. Ltd. They are capable of annealing up to 700 tons of coiled silicon steel strip per week. Each furnace, which weighs 15 tons and has a full complement of bases and hoods, is required to handle charges up to 20 tons in the form of coils of various widths wound to an outside diameter of nearly 5 feet. The coils are mounted as a stack, 8 feet or more in height, in a furnace base and are sealed under a heat-resisting steel hood, which is of lightweight construction so that the mass of metal to be heated is kept to a minimum. The furnace bell, which carries the heating elements, is then lowered over the hood and is accurately positioned by means of steel locating posts adjacent to the base.

The heat treatment is carried out at a temperature between 740° C. and 780° C., in an atmosphere of cracked and burnt ammonia, which is circulated through the charge by a fan unit housed in the centre of the furnace base and passes along an air guide and between plates which separates the coils, before returning through the centre of the coils. The air guide and the separate plates have been designed to take the "swirl" out of the atmosphere before it returns to the fan, as well as to ensure the most efficient circulation.

The furnace elements are constructed from nickel-chromium alloy strip and are wound in sinuous form. Each furnace is rated at 360 kW and has its elements arranged in 2 three-phase circuits. One circuit is automatically switched off just before the desired working temperature is reached and this 50% reduction in power input minimises the amount of temperature overshoot at the control point.

Fig. 1.—G.E.C. vertical cylindrical bell type furnaces in the Brierley Hill works of Richard Thomas and Baldwins, Ltd.

New and Revised British Standards

Steel Bars for the Production of Machined Parts (B.S. 32 : 1952)

This revised British Standard replaces B.S. 32 : 1935, which has been out of print for some time. B.S. 32 was, in effect, superseded by B.S. 970 "Wrought steels for automobile and general engineering purposes," but is, however, being retained in this 1952 edition for an interim period until the use of B.S. 970 for such material has become sufficiently established in general engineering practice, particularly overseas.

In the present revision the chemical composition and tensile properties of the steels have been made identical with those of the corresponding steels in B.S. 970. A new grade, which represents a quality superior to that associated with the obsolete Grade 3, has been added for rapid machining in repetition work. In the standard it is requested that orders should in future quote the En. number referring to B.S. 970.

Colouring and Marking of Wooden Pattern Equipment for Foundries (B.S. 467 : 1952)

Wall Chart for Colouring and Marking of Wooden Pattern Equipment for Foundries (B.S. 467 C : 1952)

This British Standard provides a simpler colour system than the first edition (published in 1932) and has one colour scheme for all patterns, irrespective of the metal in which they are to be cast. The standard gives effect to the majority of current practice and illustrates by means of a diagram and key of a typical pattern and core box, the appropriate colouring of patterns and core boxes for ferrous and non-ferrous castings. For the convenience of pattern shops a wall chart (B.S. 467 C) has been prepared; this is an enlargement of this diagram and key in the standard and should be of great help in providing easy reference for the pattern makers.

Scheme of Symbols for Welding (B.S. 499 : 1952, Section 7)

The British Standards Institution has recently published the above revised section of B.S. 499. The new scheme of symbols contains radical alterations of the former practice. It has been drafted with full knowledge and appreciation of the work to be done in the interests of international collaboration to secure co-ordination between British and American practices. It is part of a wide scheme of co-ordination which will include drawing office practice, unification of screw threads and other matters discussed at the Ottawa Conference on Unification of Engineering Standards in 1945.

Apart from the aspect of co-ordination with American practice, the scheme provides a more flexible arrangement than can be obtained from the appendix to B.S. 499 : 1939. It departs from previous practice in two fundamental respects. The terms "near side" and "far side" have been discontinued in favour of the terms "arrow side" and "other side." This not only provides uniformity with the American scheme, but overcomes the difficulty encountered in some views of welds where the former terms were inapplicable. It has also been decided that the disposition of the weld symbol relative to the reference line should be based on the American system. At the outset, this might appear to be a reversal of former practice, inasmuch as the symbol is placed below the reference line for welds on the "arrow side," instead of, as formerly, above the reference line for welds on the "near side," but this reversal is true only to a limited extent. Nevertheless, many of the features of the former scheme have been preserved.

It is emphasised that the increasing collaboration between American and British industry will lead to growing confusion if the differences between the practices in the two countries are maintained. Consequently, it is considered preferable to make the change now, even though some difficulties may be created during an interim period.

Method for the Determination of Manganese in Iron and Steel (B.S.1121 : Pt. 23 : 1951)

The principle of the method detailed in this new British Standard is solution in phosphoric-sulphuric acid and nitric acid, conversion of the manganese to the permanganic state by boiling with potassium periodate, and finishing the determination absorptiometrically.

Addendum No. 1 to B.S. 1161 : 1951. Aluminium and Aluminium Alloy Sections (P.D. 1331)

As an addendum to B.S. 1161 the British Standards Institution has just issued some notes on aluminium and aluminium alloy in the form of extruded sections which is intended to give guidance to the prospective user, who may be unfamiliar with the characteristics of the different aluminium alloys available in the form of extruded sections. These notes recommend that in choosing an alloy for a particular purpose consideration be given not only to the mechanical and structural strength of the material but also to the ease with which it may be formed and then incorporated into a structure, and its durability under conditions or service. Notes on the working and heat treatment of the various alloys and Tables of torsion constants for the sections specified in B.S. 1161 are included.

Methods for the Analysis of Aluminium and Aluminium Alloys (B.S. 1728 : 1952)

Part 2 : 1952, Magnesium (mercury cathode method)

Part 3 : 1952, Zinc (mercury potassium thiocyanate method)

These two methods form part of a programme for British Standard methods of analysis for aluminium and aluminium alloys, of which Part 1 : "Copper," was published in March, 1951. Although in some cases the methods appear to be lengthy, it should be realised that they are recommended primarily for "referee" purposes. During their preparation, check analyses have been carried out by a number of independent analysts and the reproducibility to be expected is given over the range for which the methods are recommended. The reagents required, recommended methods of sampling and test procedures are specified.

In Part 2 : "Magnesium," the method provides (*a*) for alloys having a silicon content less than 2%, and (*b*) for alloys having a silicon content greater than 2%. This

method is applicable to alloys having magnesium contents between 0·02 and 15%.

In Part 3 : " Zinc," the method is applicable to alloys having zinc contents between 0·2 and 6%. An alternative method for the determination of zinc, using a polarographic technique, is in course of preparation and will be issued shortly.

Copies of these standards may be obtained from the British Standards Institution, Sales Department, 2 Victoria Street, London, S.W.1, at the following post free prices : B.S. 32, 2s. 6d. ; B.S. 467, 2s. ; B.S. 467 (), 1s. ; B.S. 499 (Section 7), 6s. ; B.S. 1121 (Part 23), 1s ; Addendum No. 1 to B.S. 1161, free ; B.S. 1728 (Parts 2 and 3), 2s. each part.

Core Extraction Forces Required in Pressure Die Casting

By W. M. Halliday

A discussion of the numerous die and operating factors governing the scale of gripping pressures between the sides of a cored hole and the core. Short of obtaining actual test data from a finished die, the effect of some of these factors is difficult to determine. A little known but useful rule is given whereby such pressures may be reliably estimated at the design stage.

ONE of the problems most frequently encountered by the designer of dies for use in the pressure die casting process is that of determining reliably the magnitude of the gripping pressure between a moulded hole and its core plug as a result of the solidification shrinkage of the casting.

In the normal course of events, a short period of time must elapse after the injection of the molten metal into a die before the latter may be opened to eject the finished casting. This critical time interval will be conditioned by the shape and size of the casting, its wall thickness, the type of alloy, and the temperatures of the alloy and die. Sufficient time must always be allowed for adequate solidification to take place, so that the casting can be safely ejected from the die without fear of distortion or damage.

A knowledge of the gripping pressure between the sides of a moulded hole and its core plug is thus of considerable importance during the *initial* stages of the development of a die design, in order to ensure that sufficient force, and means for applying it, will be made available for the successful withdrawal of the core plug, or the stripping of the casting therefrom, during the normal ejection operation.

The determination of the *axial* force required to overcome the resistance due to the powerful radial grip of the shrinking casting on its core is necessary in order that several important design requirements may be met. These requirements are listed below.

(1) So that other critical features and elements of the mechanism may be proportioned and located to give successful operation of the core and ejector system, and to ensure a long working life to such members.

(2) So that the member itself may be fashioned robustly and fixed with adequate security to resist extraction pressures.

(3) So that the diameter, number and, to some extent, the location of the ejector rods may be determined. This applies in the case of castings which are ejected by pushing off a stationary fixed core plug, where it is usual to employ a number of small diameter ejector rods, situated radially round the core at convenient points, each impinging on the wall of the casting. The *radial* gripping pressure exerted by the contracting casting has thus to be overcome by the *axial* force imposed by the ejector rods.

(4) So that the ejector actuating mechanism may be constructed with sufficient strength and proportions to withstand such pressure without risk of failure. This is particularly important when the ejector mechanism has to be actuated manually ; gears, cams, levers, etc. may then be designed to entail the least amount of working pressure from the operator, whilst exerting maximum thrust on the casting. Similar considerations arise where no ejector rods are used, but where the core plug is of the retractable type, being withdrawn from the casting at a certain stage. Such core actuation is often effected manually by means of levers, gears, etc.

(5) So that the proper safeguards may be applied to prevent distortion, cracking or similar defects occurring in the finished die casting. Where the gripping pressure is not known, the casting may be designed with insufficient wall thickness near critical cored holes, and such strengthening features as bosses, ribs, beadings and fillets may be omitted. Failure in this respect may thus lead to over-stressing, distortion, or even complete cracking of the component walls. Such cracking, etc., may take place *before* the casting can be ejected from its core, though this is not always the case. The walls of the part may be unduly stressed as a result of normal shrinkage being arrested by intervention of the core, so that cracking may occur *after* the part is eventually removed from the core and its further *free* shrinkage becomes possible.

(6) So that operating time can be reduced when the die is manipulated during a production run. When adequate means of ejection are available for removing a casting from its core, numerous snags and minor delays often attending this operation are eliminated, and both injection and ejection can proceed smoothly according to a stricter time sequence.

(7) So that better quality die castings, particularly in respect of dimensional accuracy and uniformity of hole sizes can be produced. Where insufficient ejection

pressure is available it may lead to troubles with ejector rods or their operating mechanism. This, in turn involves some delays during ejection, so that certain castings are retained on their core plug for a much longer period than others. This affects the size of hole ultimately obtained, and variations of as much as 0·003 in. per inch of diameter may be caused thereby. For example, according to tests recently carried out by the author on certain zinc-base pressure die castings having a large cored hole (2¼ in. diameter × 4 in. long) it was found that for every 2 seconds additional time the casting was allowed to remain on the core before ejection (beyond a certain period), the size of the finished hole was increased by an average of 0·0005 in. It will be seen, therefore, that if for any reason the interval between injection and ejection is inordinately drawn out above the proper time, considerable deviations in hole size may ensue.

Difficulty of Calculating Gripping Pressure

Unfortunately, it is not easy to calculate the radial gripping pressure, nor the axial force necessary to overcome it, because of the effect of numerous imponderable and variable factors, some of which can only be satisfactorily assessed when the die is completed and put under actual production test.

These factors include such details as :—

(*a*) The physical properties of the alloy itself, i.e., its mechanical strength and degree of ductility.

(*b*) The type of alloy ; whether it is of low melting point, as, for example, tin, lead or zinc base alloys, or one of the higher melting point materials based on aluminium, magnesium or copper.

(*c*) The solidus temperature of the alloy, i.e., the temperature at which first stage skin solidification commences.

(*d*) The temperature of the molten alloy injected into the die, and the working temperature of the latter.

(*e*) The size of cored hole, particularly the ratio between length and diameter of the greatest cross-sectional dimension.

(*f*) The degree of taper or ' ejection draft ' provided on the sides of the core plug forming such a hole, and/or whether the hole is cored blind or fully through the wall of the casting. If the former is the case, considerable care has to be exercised in respect of the length of projection of the core. This should not be more than about twice its diameter, owing to the lack of support at one end. This would render the plug liable to distort during actual injection of the alloy charge, and any permanent bend, however slight, would thus increase the axial force needed to eject the casting. Where the hole is to pass completely through the wall, the core may be supported at both ends and its length can then be safely increased up to about 6 or 8 times the diameter, without incurring risk of deflection.

(*g*) The thickness of the casting wall immediately surrounding the cored hole is also very important, as if this portion is heavily massed with thick sections, the gripping pressure will be greatly increased. On the other hand, a wall section which is unusually thin, weak, and unsupported, may result in distortion and stretching of the holes, with consequent variations in size. It is, of course, possible to obviate these difficulties by the judicious use of bosses, beading, and ribs, which will often increase stiffness and rigidity at the expense of little additional weight of metal.

(*h*) The quality of surface finish and smoothness imparted to the core plug itself will also influence the force required to eject the casting. The core should be free from concentric tooling marks, slight undercuts, roughened surface, nicks or other depressions into which alloy could be injected, as to remove a casting from a core plug of such nature would entail the shearing of the projections on the casting and, therefore, a considerably increased ejection force.

(*i*) The length of time allowed between injection of the metal and ejection of the casting is also important, and it is often difficult to keep this constant during a normal production run, due to the vagaries of operator, die, machine, or all three.

(*j*) The manner of ejection : i.e., whether by rods, sleeves, or retraction of the core. If rod ejection is used, the way in which the rods bear on the side of the component, their relationship with the core plug, and their diameter are also important points.

(*k*) The difficulty of evaluating the correct modulus of elasticity of the die casting alloy at the critical temperature closely approximating to its melting point.

(*l*) The structural solidity obtained in the casting, i.e., the degree of porosity due to shrinkage, air inclusions or other cause, affects the shrinkage and gripping pressure.

(*m*) The uniformity of temperature throughout the casting. Questions of air venting, water cooling and the runner gate system are vitally concerned with this factor.

(*n*) The direction of the major shrinkage forces arising in the casting : viz., whether they are perpendicular to the core axis, or inclined thereto. As a general rule, shrinkage is not truly perpendicular to the core axis, although the deviation is so slight as to be neglected for practical purposes.

Properties of the Die Casting Alloy

In considering further some of the above factors, it will be seen that the effect of the physical properties of the die casting alloy is by no means easy to assess. With the high melting point materials, such as the copper base alloys, there is a much greater disparity between the molten metal temperature and the die temperature, which means that there is a greater temperature range over which the casting is shrinking onto the core, but the extent to which this governs the gripping pressure is dependent on the thermal expansion of the casting material, its plastic behaviour and a number of other factors.

The Effect of Ejection Taper

The customary angle of taper provided on cores ranges from 3°–5°. Smaller tapers result in the casting being unable to free itself sufficiently *early* during ejection : its removal is thus characterised by a sustained heavy pressure during the removal of the major part of the core length, instead of the more preferable initial heavy pressure maintained for the short time necessary to loosen the casting or core as the case may be.

A greater amount of taper, whilst reducing the duration of the initial heavy pressure, does not influence the magnitude of the pressure to any marked degree. A large taper may, however, be undesirable, owing to the resulting disparity in size between the two ends of the hole : a subsequent machining operation might then become necessary.

Variation of core taper, above or below the conventional limits is, therefore, without important effect on the pressure required to loosen the core initially, but an adequate degree of taper greatly assists in obviating scoring of the surface during ejection, and this is helpful in ensuring smooth ejection with minimum pressure.

Ejector Rods

The location of ejector rods relative to the critical core and the side of the casting is equally important. Each rod should be so disposed that it takes its proper share of the ejection load, and the members should be carefully pre-set so that all rods act on the side of the casting with equal pressure.

Where one or more rods are set back a slight amount relative to the other rods, they do not contact the casting at the same instant as the others, with the result that the axis of the hole in the casting may be twisted relative to the axis of the core. Such slight twisting considerably increases the force needed to withdraw the core. This, incidentally, is one operating factor which has to be continually and closely watched during a production run, especially where the ejector rods are very small in diameter and liable to distortion, rapid wear, or easy disturbance in their setting.

Where ejection is accomplished by withdrawing the core from the casting and die block, instead of pushing the casting off the core by rods, the line of travel taken by the core must be exactly coincident with the axis of the cored hole. With the core mounted in a retracting slide, this is sometimes difficult to ensure, due to wear and slackness occurring on the slide surfaces.

Both of these conditions result in a considerable increase in the ejecting pressure required, and may cause delays in the normal ejection of the finished article.

Speed of Ejection

If ejection can be effected almost instantly after injection and skin solidification of the casting, as is usually possible with the simplest die constructions and component shapes, so much the better. Very rapid ejection ensures the minimum temperature difference between the solidus and extraction stages: the casting will thus shrink the minimum amount on to the core, and the gripping pressure will be commensurately less. If, however, ejection has to be delayed for any appreciable time, as is often necessary to allow other parts of the die mechanism to be actuated, cooling and shrinkage continue and the gripping pressure is thereby increased.

Speed of ejection is usually controlled by a number of factors other than the temperature of casting, and these include the type of ejector mechanism: the length of cored hole and the extent of travel of the ejectors: the amount of die-opening movement; and the character of the casting shape—wall thicknesses, disposition of cored holes, etc. To maintain the gripping pressure between the hole and core at the lowest level, it is essential to evaluate all these factors very carefully, to ensure that ejection begins as quickly as possible after injection and skin solidification.

Calculation of Gripping Pressure

Although many of the foregoing factors are incapable of accurate determination before the die is actually constructed and put under test, and must, therefore, be estimated, it is possible to calculate theoretically the unit radial gripping pressure between the sides of a cored hole and its core plug by means of certain formulae which have been established. These formulae are, however, very cumbrous and the calculation is somewhat laborious. Moreover, they include a number of values which at best can only be approximations, at least in the initial development stages before the die construction is commenced. Since it is at that stage that the information will be of most value, it seems problematical whether the results obtained are of sufficient value to the designer to be worth the effort involved.

An extremely useful and far simpler, though less well-known, formula, which is capable of being applied during the preliminary development of the die design, and which gives more reliable results is:—

$$P_a = 8DLVS$$

where

- P_a is the axial force required to overcome the radial gripping pressure, i.e. the ejection force,
- D is the core diameter,
- L is the length of core projecting into the casting wall,
- S is the average thickness of the wall section immediately round the cored hole, and
- V is a variable factor having the following estimated values for the different die casting alloys: aluminium 15; zinc base 22, copper base 25.

It will be observed that this rule gives directly the axial force required to extract the core.

In applying the results obtained by these calculations and to take proper cognisance of the several variable factors mentioned earlier, it is advisable to employ a suitable factor of safety. Thus, for zinc base alloys and similar low melting point metals, the calculated value of P_a should be increased by 20–25%, whilst for the high melting point alloys an increase of 25–35% would be advisable to ensure a sufficient reserve of force.

By the use of such factors of safety, the results obtained by the above method afford the designer reliable guidance in determining the essential proportions of die members, especially the ejector rods and the actuating mechanism which must be capable of overcoming the gripping pressure on the cores.

This simple rule may also be used in respect of inserts to be moulded in the wall of a casting. Where such inserts have to be hollow, or of slender proportions, it is advisable to have an idea of the grip due to the normal contraction pressure of the solidifying casting. This will often assist in determining the size of the inserts, the keying methods to be adopted, and the manner of supporting such parts in the die cavity by pins of adequate proportions.

Interested readers are referred to the fuller and more detailed treatment of the underlying complex theoretical calculations for determining gripping forces, as given in *Machinery* (20th March, 1947) by H. K. Barton, to whom the author acknowledges his indebtedness for the useful empirical rule mentioned above.

Extended Hours of Opening Continued at Patent Office Library

It has been decided to continue the extended hours of opening of the Patent Office Library at 25, Southampton Buildings, Chancery Lane, W.C.2. The hours are 10 a.m. to 9 p.m. Monday to Friday and 10 a.m. to 5 p.m. Saturday. The extended hours of opening were first introduced on May 7th, 1951.

Temperature Controlled Flame Hardening

AN important development in the art of surface hardening of steel was introduced into this country recently when Surfard, Ltd., of London, demonstrated the Peddinghaus oxy-town-gas system of flame hardening.

There are many instances where a component having a hard, wear-resistant surface in combination with a tough core is called for, and the methods available for attaining these properties in steels include case hardening, nitriding, induction hardening and flame hardening. Each process has its own advantages and limitations, and flame hardening offers attractive possibilities for the production of local hard surfaces where large machine parts are subject to wear. At the present time, when appropriate grades of alloy steel for case hardening or nitriding are difficult to obtain, perhaps the most commercially attractive and economically important feature of the process is that straight carbon steels are just as effective as alloy steels in the majority of applications. This is achieved by using straight carbon steels which already contain enough carbon (say 0·35–0·70%) to harden to the desired extent (450–850 V.P.N.) and by applying intense heat locally for a very short time, so that only the surface material reaches the hardening temperature. The depth of the hardened case depends on the rate of heat input and on the short space of time between cutting off the heat and applying the quenching medium—usually water or soluble oil. The properties of the slightly heated core remain virtually unchanged, the tensile strength ranging according to carbon content from 35 to 50 tons/sq. in. if the material is initially in the normalised condition. Higher core strengths, coupled with a high rate of response in surface treatment, are obtainable by using material initially in the hardened and tempered state, but the added cost of such conditioning heat treatment is rarely justifiable. Cast iron, semi-steel and blackheart malleable iron all contain sufficient carbon to enable them to be surface hardened in this way to increase resistance to wear.

Of the many suggested methods for carrying out this type of surface hardening, only two—flame hardening and induction hardening—are used in practice. The latter permits easy control of heat input and has much to commend it where the area to be hardened is relatively small and where very large numbers of similar parts are to be treated. On the other hand, flame hardening shows to advantage where large areas are to be hardened, and where there are more frequent design changes in components.

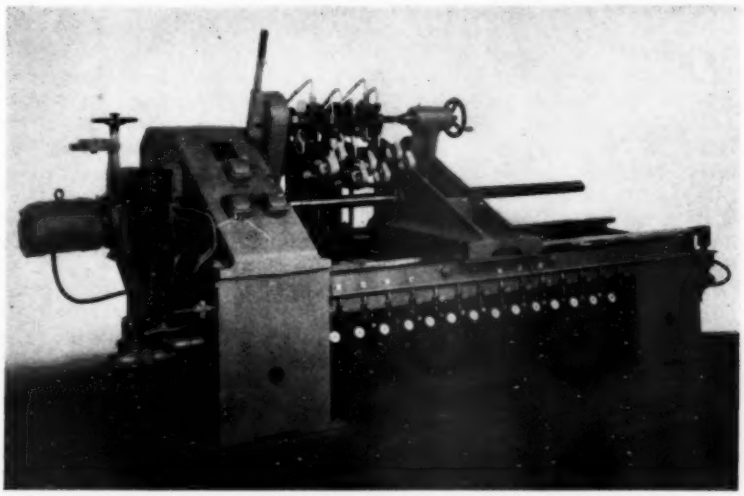
Gases used in Flame Hardening

In order to develop a flame of sufficient intensity to heat the surface layers of steel, without undue penetration, an oxygen-fuel gas mixture is required. This led Sumter and Shorter, thirty years ago, to adopt the high intensity oxy-acetylene flame, as used for welding. Although this practice became almost universal in this country, on the Continent and in America, several investigators have shown that the oxy-acetylene flame, whilst admirably suited to welding at 1,500°–1,600° C., is really far hotter than necessary to raise the surface of steel to its hardening temperature of 800°–850° C. The Peddinghaus Organisation have proved conclusively that the oxy-town-gas flame gives ample intensity for surface hardening, and have designed and manufactured special burners in conjunction with a wide range of flame hardening machines. The consumption of oxygen for a given job is the same whether town-gas or acetylene is used.

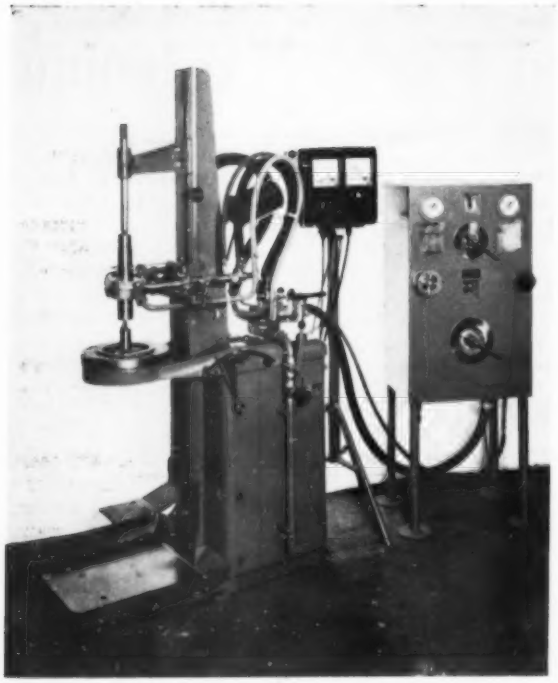
Control of Temperature

The main problem in flame hardening has always been the human element in judging the critical temperature to which the workpiece must be heated. If the correct hardening temperature is appreciably exceeded, grain coarsening of the case may occur and seriously affect its properties. In types of steel sensitive to hardening temperature, the overheated layer may crack or even flake off when quenched. Some means of measuring the temperature would, therefore, be extremely useful, but the heating of the steel is so rapid that the use of ordinary pyrometers is out of the question, owing to the slow response of direct indicating instruments, or the time required to adjust the disappearing filament type.

To overcome these difficulties, the Peddinghaus Organisation has developed the Milliscope. By its novel design, this device enables temperature rises far in excess of the heating speed to be measured within fine limits. This makes it possible, by linking the instrument to a Peddinghaus flame-hardening machine, to obtain precise automatic control of hardening temperature. Long runs of components may be accurately and consistently hardened and the human element in the estimation of temperature, eliminated. Even if the Milliscope is not coupled to a flame-hardening machine so as to make the process completely automatic, the



Seven bearings of a crankshaft being hardened simultaneously by a Peddinghaus KU125 automatic machine using oxy-town-gas.



Peddinghaus vertical oxy-town-gas hardening machine SH81 showing the Milliscope automatic temperature control and the gas flow meter.

instrument is of great assistance to the operator. It gives him warning of the approach of the critical temperature and then accurately indicates the moment at which it is reached.

Principle of Operation of the Milliscope

The instrument comprises two main parts; the working head—fitted with a water cooling device which might be necessary when working with large heat radiating surfaces—and the control panel. It is similar in principle to the disappearing filament optical pyrometer, except that a special photocell is used to compare the radiation from the comparison filament and from the work surface. The temperature of the filament is set by means of a rheostat and an image of it is focused on the photocell, the optical path being interrupted by a rotating chopper disc. This disc has circular holes around the periphery and is so arranged that it alternately exposes the photocell to an image of the work surface and to an image of the comparison filament. The radiation from these two sources is thus continuously compared and, by the introduction of optical light filters, the comparison is made in a particular wavelength range. If a difference exists, an alternating current is produced by the photocell, the phase of which is indicative of the direction of unbalance.

The radiation from the comparison filament can be adjusted by variation of the current passing through the filament. Since the radiation from the work surface is related to its temperature, it will be seen that, for a particular setting of the comparison filament current, there will be a particular work surface temperature at which no alternating current is produced by the photocell. At this point the direct current generated is utilised to actuate switches on flame-hardening machines so as to render them automatic in action and to control closely the hardening temperature.

The photocell current is amplified and applied to a phase sensitive rectifier, which is arranged to operate a relay so that, when the work temperature reaches the value set, the relay is operated. This controls, in some cases of progressive hardening, the speed of the burner and quench and, in other cases, it actually changes the position of the component being treated from the heating to the quench position.

By means of a signal lamp and moving needle, the Milliscope indicates to the operator precisely what the conditions are. At the commencement of heating a blue signal lamp is illuminated and, as the temperature approaches that at which the instrument has been set, a needle indicator on the control panel passes through a large scale as a warning that the required temperature will soon be reached. At a point approximately 10° C. before such temperature is attained, the blue signal disappears. At the moment when the temperature of the work equals that of the filament, the needle reaches zero and at about 10° C. above a red signal is shown, the needle continuing to move beyond the zero point to indicate the deviation.

As the accuracy depends upon the stability of the comparison filament lamp, the lamp is arranged to run at 1/10th of its nominal output, except when sighting the filament on the job to be heated. Then more current is permitted to pass to the filament in order to make its image visible on the spot from which the temperature will be measured.

The distance between the flame-hardening machine and the working head of the Milliscope is usually between 12 in. and 30 in. according to the surface area to be measured. For example, at 27 in. an area of $\frac{5}{8}$ in. diameter is covered; with another set of lenses, it is possible to measure an area as small as 3/64 in. diameter at a distance of $4\frac{3}{4}$ in.

Whilst primarily designed for flame-hardening control, the Milliscope can be employed for numerous purposes, such as normalising and relieving stresses in welded joints. It can be used to control and maintain temperatures down to 200° C. with accuracy.

Available Machines

The Peddinghaus range of machines is indeed comprehensive, covering the hardening of all kinds of parts from huge gears and crankshafts to small pins and spindles. One special purpose machine automatically hardens seven bearings of a crankshaft at once. Recently demonstrated in London was a machine of the vertical type in which components ranging from small spindles up to rolls of nearly 5 in. in diameter and 24 in. long could be progressively hardened. The component is held between centres and rotated at about 100 r.p.m., two semi-circular oxy-town-gas burners, having a narrow slit which emits a ribbon of intense flame, are used for the heat input. These burners, and the quenches which are situated below them, are mounted on a carrier which is raised hydraulically throughout the length of the part to be hardened. On this carrier is mounted the " working head " of the Milliscope which is sighted on to the portion of the work being hardened, close to the zone of heat produced by the burners. In this way, the Milliscope follows this zone throughout the travel of the burner. Naturally the faster the burners rise, the lower the heat

input to the component and vice versa. The speed of the burner rise is set slightly slow so that the tendency is for the temperature of the work to exceed the pre-set value. Immediately this happens, however, the direct current generated by the Milliscope causes a magnetic valve in the hydraulic system to permit more oil to pass to the cylinder, so increasing the speed of the burner travel and thereby reducing the temperature. This results in uniform degree and depth of hardness, concentricity being assured by the rotation of the component.

Electrical Plant for the Metal Industries

CONTINUING our review of recent electrical plant installations for the metal industries, we deal in this issue with the activities of the Metropolitan-Vickers Electrical Company Limited during 1951. The bulk of the equipment was connected with rolling mill drives, although a number of interesting auxiliary drives were also put into commission.

Main Drives.—Rolling mill main drives accounted for the despatch during the year of machines amounting to a total of 27,000 h.p. (r.m.s.).

Two 3,100 h.p. Ward-Leonard-Ilgner equipments were supplied for blooming and section mills in Turkey, whilst construction for use in this country included seventeen D.C. motors totalling more than 6,000 h.p. for a reconstructed skelp mill in the Midlands, and five A.C. motors with a combined h.p. of 18,250 for the roughing drives of an 80 in. tandem hot strip mill in South Wales. For the aluminium industry in this area, a 1,600 h.p. reversing slabbing mill, a three-stand tandem mill having three 1,500 h.p. D.C. motors with 450 h.p. drum coiler and two 75 h.p. uncoilers, and a number of live-roll motors (Metadyne Ward-Leonard controlled to match the ingoing and delivery speeds) were put into commission. In an interesting wheel mill plant started up in the North-West, there are 400 h.p. motors on the top and bottom edgers, supplied from a three-wire 650 kW D.C. generator, a 150 h.p. back roll motor supplied from a 125 kW three-field shovel-characteristic generator, an electrically driven rotary-hearth billet furnace, and auxiliaries including an 8,500 ton main press and punch press, dishing press, roller tables and solenoid-valve controlled hydraulic handling plant. Plant under erection in the Midlands includes a four-high non-reversing cold mill with grid-controlled rectifier supplying an 800 h.p. D.C. mill motor, together with Ward-Leonard controlled screwdowns, and a similar reversing mill for rolling silicon steel strip having also a 330 h.p. reel drive with a standard Metadyne tension control from separate generators. Three aluminium foil mills of 135 h.p. each with mechanically driven tension reels are now in production and in a Midlands steelworks a 630 h.p. D.C. drive on a 15 in. reversing bar mill has been commissioned, and two further mills with 600 h.p. and 250 h.p. D.C. drives supplied from a common generator are nearing completion. A rectifier-supplied 650 h.p. D.C. drive on a five-stand three-high 13 in. finishing mill in the north of England is now in operation. For a South Wales steelworks, a sheet temper mill and two non-reversing coil temper mill drives are being supplied, each mill having a 1,000 h.p. D.C. motor on the main drive; the first equipment, which has been started up, is fed from an 800 kW grid-controlled rectifier, but the other two will be Ward-Leonard controlled.

Main drives totalling 18,250 h.p. in the motor room of the tandem hot strip mill at the Abbey works of the Steel Company of Wales—1,250 h.p. and 3,500 h.p. induction motors on the scale breaker and broadside mill, and three 4,500 h.p. synchronous motors on the roughing mill.

Overseas, a 2,500 h.p. equipment for an 80 in. sheet mill has been successfully commissioned in Australia and is now being converted into a reversing cold strip mill by the addition of two 1,000 h.p. tandem reel motors, while a 400 h.p. four-stand bar-mill has been put into service in Portugal; these drives are D.C. Ward-Leonard controlled.

Work is in hand on a 32-in. reversing mill equipment for South Wales comprising a 4,000 h.p. D.C. motor, Ilgner set and switchgear together with auxiliary drives from the ingot chariot to the bloom-shear runout tables; the manipulators and screwdowns have Ward-Leonard Metadyne control. This new roughing mill is part of a complete modernisation scheme, for which M-V orders cover the h.v. and l.v. distribution switchgear, auxiliary

motors for the finishing mill, and the electrical equipment for a new rotary billet shear, employing electronic control to give high accuracy when billets are sheared 'on the fly.' Two 6,700 h.p. reversing mill equipments on order for export are to replace existing steam drives. A four-stand tandem cold strip mill is to have four 1,000 h.p. D.C. motors together with a 300 h.p. reel motor, motor-generator set, control and auxiliaries; the mill will roll strip up to 14 in. width at a top speed of 2,100 ft./min. A 2,000 h.p. 125/187·5 r.p.m. 48/32-pole synchronous induction motor with VAX control now nearly completed has an overall diameter of about 17½ ft. and is probably the largest two-speed 11 kV synchronous induction motor ever ordered. A 2,500 h.p. reversing strip mill for rolling silicon steel in South Wales will have tension reels equipped with 1,000 h.p. D.C. tandem drives, and a 1,000 h.p. non-reversing aluminium strip mill for the same area will have a 200 h.p. coiler and a 50 kW decoiler.

Equipment for an experimental reversing cold strip mill for the Midlands, now in an advanced state of manufacture, will have special features to give extreme versatility, for instance, an electronic Metadyne speed-regulating system to hold the speed accurately at as little as 2% of full speed.

Among orders received for main drives during the year is a four-high non-reversing 42 in. cold sheet mill equipment for the Midlands, covering a 300 h.p. D.C. Ward-Leonard main drive and the screwdowns, control gear and switchgear. A new tube plant equipment will comprise five D.C. motors—three of 2,000 h.p., one of 1,500 h.p. and one of 1,000 h.p.—with two flywheels and control gear, each motor being supplied by a grid-controlled rectifier; ten rectifier equipments are on order, ranging from 20 kW glass bulb units to 1,600 kW pumpless steel tank units, and in many cases with grid control of voltage for starting, automatic voltage regulation, and load limiting. Two rotary flying billet shear equipments have been ordered, one for the North-East Coast and one for India, the former being the first Morgan type shear for which British electrical equipment has been specified; Metrovick is supplying the only three equipments that have so far been ordered in this country.

Auxiliary Drives: Auxiliary drives shipped or commissioned during the year include thirteen processing lines for tinning, cleaning, pickling, shearing and classifying tinplate, steel strip, or aluminium strip in South Wales. The electrolytic cleaning lines, of which the first of two for a large steelworks is now installed, run at 2,000 ft./min. and clean strip steel from the tandem mill. A notable feature of the installation is the photo-electric system, which provides smooth and continuous automatic control of the loop formed by the strip as it leaves the uncoiler; at the end of the line, tension is maintained on the coiling reel by Metadyne and magnetic amplifier control (as used on single-stand and tandem strip mills). Control gear is being supplied for a third trimming and shearing line, complete with classifier.

For another plant of the same Company many standard D.C. motors with Ward-Leonard control were supplied, together with heavy duty steelworks auxiliary motors (for the 80 in. mill already mentioned) and a plate-shearing line comprising depressing roller, rotary shear, approach table, straight edge machine, magnet shifter, rotary scrap shearer, leveller run-out, and side trimmer. Control gear was also supplied for the pickle line, which processes steel strip at 400 ft./min.; the loop in the tanks is controlled by a dancing roller rheostat.

The new steelworks auxiliary motors type MDN, designed to conform to the American '600' series, are being supplied in quantity for driving roller racks, screwdowns, manipulators, side guards, tilting fingers, flying shears, and other main mill auxiliaries. Orders have also been received for items from the new range of Metadyne generators, particularly for the control of strip mills over a very wide range of speed and load.

A new semi-automatic ingot chariot drive with Metadyne magnetic amplifier control has been commissioned, and two Ward-Leonard blast furnace hoists put into service, one being fully automatic with remote control of charging. Control gear for four blast furnace automatic charging equipments has been commissioned during the year, one of the bucket type and three of the skip type with full sequence control for bells, sounding rods, and distributor. Orders for blast furnace equipment received during the year include three new hoists, for the North-East Coast, the North-West and the Midlands; the first is an A.C. hoist with manual operation, whilst the others are D.C. with automatic control of skips, starting, distributor sequence, and main bell operation. Electrical equipments are in hand for a large number of scale and transfer cars. At a new sintering plant the fans will be driven by three 225 h.p. squirrel cage motors through hydraulic couplings.

For a copper works in the north of England motors and control gear are being made for two drawbenches requiring a total of 900 h.p.

Heavy duty control gear developed for the metal industries includes an overcurrent relay and a rheostat.

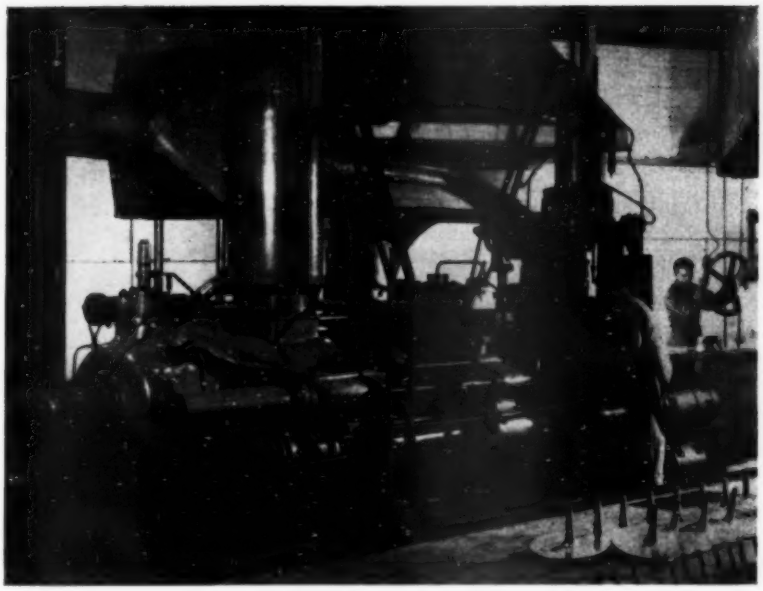
Supply and Distribution: A number of items of switchgear were supplied to metal works and two complete reorganisation schemes are in hand—one for the power distribution for an iron foundry in the South of England, including h.v. and l.v. switchgear, transformers and sub-distribution, and the other for the sub-station equipment including power factor correction gear at a steelworks in the North-West.

Swedish H.F. Steel Melting Installation

Two fully automatic high-frequency furnaces, with a power rating of 3,400 kW. each, a steel-charge capacity of 12 tons, and a melting time of two and a half hours, claimed to be the largest of their kind in the world, have recently been put into service by the well-known Swedish Bofors Works. The installation, which comprises three identical 12-ton furnaces and one 3-ton furnace, has been designed and built by ASEA, Sweden's leading manufacturers of electrical equipment.

Measuring 1,600 mm. in diameter and weighing more than one ton, the 18,000 ampère coil of each furnace consists of copper tubes, which are cooled by 500 litres of water per second. Incidentally, part of the cooling water, which has a temperature of approximately 70° C. (158° F.) after passing the coil, is utilised for the shower-bath in the workers' changing room. The high-frequency 600-cycle current is supplied by two generators and a transformer and is transmitted to the furnaces by means of a conductor system containing over 40 tons of copper and 170 cables with a total length of 4,000 metres.

New H.D.A. Pressure Die Casting Foundry at Slough



The largest pressure die casting machine in Britain shown here is capable of producing castings weighing 30 lb.

AS a result of the rapid increase in the demand for light alloy pressure die castings which has taken place during the last few years, it became obvious to High Duty Alloys Ltd. that if they were to be in a position to meet all their customers' requirements, a much larger production capacity would be required. After a thorough study of technical information and improvements compiled over a period of years, a layout was produced and a pressure die casting foundry built which, it is claimed, is the most up-to-date in the world.

The layout was the subject of very careful consideration and experimental work, in order that the foundry's 7,600 square feet should be used to the utmost advantage. No attempt was made to compromise with existing structures and the pressure die casting foundry is in effect a new building, with a clear 20 feet from floor to roof truss, wide entrance and exit doors to expedite traffic, and high level lighting over the whole area. Particular attention was paid, in deciding the layout, to the avoidance of bottlenecks, awkward corners and unnecessary journeys.

A further problem which had to be most carefully considered was the question of new plant and machines. It was most essential that the new and old should blend.

A view of part of the new pressure die casting foundry.

so that a complete production range could be made available at the most economic figure. It was also decided that an increase should be made in the size of casting which could be produced by the pressure die casting method. To achieve these ends, extensive investigations with the capabilities and characteristics of individual machines were undertaken, and as a result of all this work, castings ranging in weight from 1 ounce to 30 pounds can now be produced.

One factor of obvious importance to a smooth sequence of operations was that of the relationship between the foundry bulk furnaces and the gas-fired holding furnaces and between the latter and the die casting machines. Rigid precautions are taken to ensure the specification of all alloys used. Material reaches the foundry bulk furnaces in ingot form after analysis by the laboratory and, after melting, is submitted once more to mechanical and analytical tests. It is then carried by overhead cranes to the individual holding furnaces, each situated so as to reduce to a minimum the amount of movement required by subsequent operations.

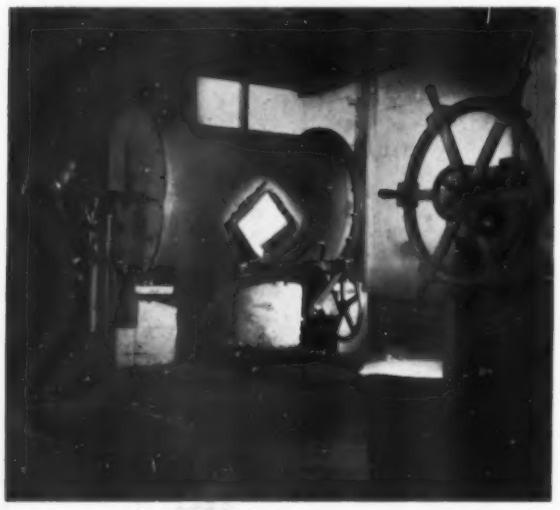
Much thought has also been given to the question of maintenance, to ensure that production continues in the case of individual breakdowns. All services, such as gas, compressed air, temperature-recording circuits, inlet and return hydraulic pipes, etc., each with its identifying colour, are carried in specially constructed trenches in the floor, accessible at a moment's notice by the simple operation of removing a portion of the chequer-plate cover.

Good working conditions are regarded as just as important a factor in efficiency as mechanical and technical perfection or analytical control. Besides the provision of an efficient layout—unnecessary journeys, awkwardly placed controls and tedious delays all cause fatigue and loss of interest—the Company has been at pains to make the new foundry a clean and pleasant place in which to work. Of particular interest is the fume extractor, with which each machine has been individually equipped, with specially designed filters to prevent fire caused by the ignition of residual oil, and ducts to remove any unpleasant elements from the atmosphere. In many other ways the workers in this new shop have first rate working conditions.

Spraying the die faces.

As will be seen from the general view of the foundry, the die casting machines with their individual holding furnaces are set out in herring-bone fashion along the shop, the holding furnaces forming two lines, one on each side of the centre gangway. The machines are Polak hydraulically operated units working under a pressure of 1,700 lb. sq. in. There are six Type 600, three Type 900/13, one Type 2255 and one Type 5065. A 3-ram hydraulic pump delivers a mixture of soluble oil and water to an accumulator which is charged with nitrogen and stores the water under pressure from the pump until such time as it is supplied at the required speed to the casting machines. The two bulk melting furnaces, made by N. C. Ashton Ltd., are located at the end of the shop, under the hoods seen in the illustration. They are oil-fired, each having a capacity of 3,000 lb., and metal is delivered from them to the Radiant Heating gas-fired holding furnaces by overhead crane, as has already been mentioned.

At the moment it is a little difficult to give a definite figure for the foundry output but it is estimated to be in the region of 80 tons per month, working two 8-hour shifts.



Pouring from one of the bulk furnaces.

Unionmelt Automatic Arc Welding

THE Quasi-Arc Company Limited, Bilston, Staffordshire, announce that as from 1st April, 1952, sales and service of Unionmelt automatic welding plant, powder and wire will be transferred to their Associated Company, Fusarc Limited, Team Valley, Gateshead-on-Tyne, 11. Fusarc Limited, will continue to supply complete mechanised welding installations, including manipulators and other appropriate forms of handling equipment, as well as automatic welding heads embodying either the Fusarc continuous covered electrode system or the Unionmelt submerged arc system of automatic welding. Skilled Unionmelt welding personnel are being transferred from The Quasi-Arc Company Limited, to Fusarc Limited, and users of the Unionmelt process can be assured of full continuity in service and supplies.

Correspondence

Metallising of Plastics

The Editor, METALLURGIA.
Dear Sir,

It was with great interest that I read the paper "Notes on the Metallising of Plastics" by Mr. D. McPherson in the December 1951 issue.

I feel that his remarks about the poor adhesion of silver films produced by the reduction of ammoniacal silver nitrate solutions are not fully justified, particularly as such methods are being used quite extensively in industry. It is readily admitted that silver films are sometimes produced with poor adhesive strength, but in the majority of cases, it is possible to trace the cause—poor pre-treatment. As with all metal finishing operations, the adhesion of the deposited film depends largely on how efficiently cleaning and etching, etc., have been carried out.

In the preparation of plastics for plating, it is essential that the surface glaze be removed; methods such as light sand blasting[1] or tumbling in a barrel with sand or pumice[2] have been suggested. The plastic should then be cleaned and etched. It has been claimed[3] that adhesion can be improved if a substance possessing both polar and non-polar groups, such as organo-metal halogenides or metal halides, is used to produce an interfilm. The method suggests that these substances, having an affinity for organic materials yet hydrolysing in the atmosphere, form inorganic polar groups to which the silver film adheres.

Mr. McPherson has only made a passing reference to metal spraying, but this method has been used with success, nor has he mentioned methods of incorporating copper or other metallic powders with the plastic before moulding. Another method which has not been described in these "Notes" is the application of a graphite dispersion[4] followed by direct copper plating.

One of the best papers on this subject is by H. Narcus,[5] another is the paper by Upton.[2]

Blum and Hogaboom[6] state that the adhesion of metallic deposits on plastics is not equal to that on metals due to the following factors:—

1. No strong bond exists between the plastic and the film.
2. If such a bond did exist the tensile strength of the plastic would be less than that of the deposited film.
3. The differences in the coefficients of expansion; for example, if the deposit is polished, the plastic will expand and may stretch the deposit, on cooling the deposit may blister.

I trust that this information will be of use to those interested in the plating of plastics, and be complementary to the information given in Mr. McPherson's paper.

Yours faithfully,
P. A. CARTWRIGHT.

Heaton Chapel,
Stockport. 21st February, 1952

1 "Handbook of Electroplating," Messrs. W. Canning & Co., Ltd., (17th Edn.).
2 "The Metallization of Glass and Plastics by the Reduction of Aqueous Solutions," by P. B. Upton, *J. Electrodepositors Tech. Soc.*, 1947, **22**, 45–72.
3 Kodak, Ltd., B.P.'s 635,101 and 635,102; *Electroplating*, **3**, 11, 1950, 425.
4 Information Sheet B.1 issued by Acheson Colloids, Ltd.
5 H. Narcus, *Trans. Electrochem. Soc.*, **88**, 1945, 371, etc.
6 "The Principles of Electroplating and Electroforming," by Blum and Hogaboom, McGraw-Hill, 3rd Edn., 234-235.

The Editor, METALLURGIA.
Dear Sir,

Although your correspondent, Mr. P. A. Cartwright, rightly draws attention to certain omissions in my recent article, it should be pointed out that it was deliberately headed "Notes." I must, however, thank him for the further information he has supplied and for the constructive nature of his criticism.

Mr. Cartwright appears to have the advantage of me in that I do not know of any extensive use in industry in this country of such methods as he describes. I do know, however, that attempts have been and are still being made to commercialise such methods, but there have been recent examples of firms running into financial difficulties, in spite of having up-to-date equipment and some very able technicians, in attempting to adapt wet silvering methods to the metallisation of plastic materials. I do not dispute that a good deal of decorative rubbish has been foisted on the public as metallised plastic, but this is more a reflection of the vagary of public taste than a matter for academic consideration.

Mr. Cartwright's emphasis on surface preparation is of course relevant and important, but it does not alter his own quoted remark from the paper by Blum & Hogaboom, that "no strong bond exists between the plastic and the film" even after all possible precautions (such as he has suggested) have been taken. The reference to stannous chloride swabbing and the use of other compounds such as detergents are likewise only devices which affect the degree of efficiency of a process which is basically inefficient.

The incorporation of adulterants such as copper powder, graphite and other conducting media, has, I agree, been extensively investigated and many colourful stories have emanated from the U.S.A. It is as well to remember, however, that technical journalism in the States is a very much more remunerative profession than actual research, and many of the 'Digest' type of science papers are more literary than scientific. The important factor in adulteration methods is that adulterants, to be effective, must be added to moulding powders, etc., in such a proportion as to influence seriously the already inadequate physical properties of the plastic material. Interspersed conductive nuclei in a matrix of non-conductive material are insufficient to give any appreciable advantage.

However, the position is not hopeless. A method has been devised in which a conducting microfilm of silver can be alloyed to certain plastic materials providing an interfacial adhesion which defies the stress pull of even the most highly stressed electro-deposits. But I can assure Mr. Cartwright that it has not been possible by any of the methods either he or I have referred to.

Yours faithfully,
D. MCPHERSON.

Welshpool,
Montgomeryshire. 27th February, 1952.

Aluminium Coating of Steel

The Editor, METALLURGIA.
Dear Sir,

I noted with interest the paper entitled "The Coating of Steel with Aluminium" which appeared in your February issue. Such a summary of present day processes is very interesting and of value. In view, therefore, of the wide interest which may attach to this

article I feel bound to draw your attention to some rather misleading references to the application of aluminium by metal spraying.

The principal methods of aluminium coating are correctly listed in order of decreasing industrial importance, but when metal spraying is dealt with more fully, the molten metal, powder and wire processes are described in that order, which is exactly the reverse of their position in industry to-day. The great tonnage of aluminium is applied by the wire process with the powder process running a close second, while little or no aluminium is applied by the molten metal method which is better suited to low melting point metals. The three methods were all originally developed by Schoop and his fellow workers and are given in order of their development. During the early stages of commercial development the wire process gained favour and became known as the "Schoop process." I should like to point out also that the photomicrograph of the sprayed aluminium coating is not a very good example of a sprayed deposit. Moreover, it does not exhibit very clearly the characteristic structure obtained by the spraying process.

In the section entitled "Calorising and Heat Treatment of Sprayed Coatings," there are some statements which may give the reader a wrong impression. The heat treatment of sprayed coatings is not known as "Calorising" but by the name of "Aluminising." The calorising process is that in which a coating is obtained by cementation effected by packing the articles in aluminium powder followed by heat treatment.

The methods for prevention of oxidation during heat treatment are all in present day use to some extent, but that using aluminium wire containing 0·75% cadmium is the one most widely practised by my company. Fig. 2 is stated to be a cross section of a calorised coating whereas it is, in fact, an aluminised layer obtained by the above mentioned method. Unfortunately, the use of the term "Aluminised" gives rise to confusion when it is also used to describe hot-dipped material and television tubes.

Finally, I should like to point out that the proceedings of the Corrosion Committee are usually only available to members of the committee. A more appropriate reference therefore to the opinion of Dr. Hudson (32) is the paper by Hudson and Banfield entitled "The Protection of Iron and Steel by Metallic Coatings, Results of Five Years' Exposure Tests." *Journal of the Iron and Steel Institute*, No. II, 1946.

Yours faithfully,

SHEILA M. HOLGATE, L.I.M.,

Metallisation, Ltd.,
Dudley. 29th February, 1952.

The Editor, METALLURGIA.

Dear Sir,

The keen interest shown by Miss Holgate in our paper, "The Coating of Steel with Aluminium," which appeared in your February issue, is very gratifying indeed. The accusation that effect had been given to the use of some rather misleading references to the application of aluminium by metal spraying, however, is not strictly accurate, and we would like to make the following comments.

Miss Holgate points out that the three spraying methods are given in order of their development. That is precisely what we intended to convey to the reader. The principal methods for applying aluminium coatings to steel are given in order of decreasing industrial importance, but in describing one particular method involving more than one process, it is only natural to deal with these in order of development. This has been done throughout the paper. Furthermore, successful development of any process entails the introduction of one or more beneficial advantages to producer and consumer alike, hence, in reading the text we would have imagined that the reader would have obtained the impression that the wire process is undoubtedly the foremost in its application. We agree that the micrograph exhibited is not a very good example of a sprayed deposit, but this was the best available in the short time at our disposal.

In connection with the use of the terms "Calorising" and "Aluminising," we would like to point out that we fully appreciate that the original meaning of "Calorising" describes the application of an aluminium coating by packing the articles in aluminium powder followed by heat-treatment. Heat-treatment of sprayed coatings to produce alloying with the base of necessity involves solid diffusion, and as the resulting coating is not very different from a truly calorised coating, we feel justified in classifying heat-treated sprayed coatings as a calorising process. Perhaps, to avoid confusion, we could have employed the term, "Spray-Calorising."

Miss Holgate uses the term "Aluminising" to denote the heat-treatment of sprayed coatings, which is a duplex process involving spraying followed by subsequent heat-treatment. We prefer to accept "Aluminising" as a process whereby aluminium coatings are produced by hot-dipping techniques. This is more in line with the accepted ideas that "Galvanising" and "Tinning" imply hot-dipped coatings as distinct from "Electro-Galvanising," "Electro-Tinning," etc. Hence, the inclusion of Fig. 2 of a heat-treated sprayed coating under "Calorising."

Lastly, we thank Miss Holgate for suggesting a more appropriate reference to Dr. Hudson's opinion on Corrosion Testing in the paper by Hudson and Banfield.

Yours faithfully,

D. P. MOSES, G. G. POPHAM.

The British Iron and Steel
Research Association,
Sketty Hall, Swansea. 5th March, 1952.

Sir William J. Larke Medal

THE Council of the Institute of Welding has conferred the Sir William J. Larke Medal, the highest award of the Institute, upon Mr. W. S. Atkins, B.Sc., M.I.C.E., M.Inst.W., for his paper "Continuous Welded Structures—Abbey Works, Port Talbot." Papers highly commended by the examiners were those of Mr. J. Latimer on "Automatic Welding" and Mr. A. R. Moss on "The Welding of Cast Iron."

Mr. W. S. Atkins is the head of the firm of consulting engineers responsible for the design of the new Abbey Works of the Steel Company of Wales Ltd., at Port Talbot. His paper, which describes the principles of design and method of construction of the buildings, all of which are fully welded was presented to the Institute of Welding last year and published in the *Transactions* of the Institute for April, 1951.

NEWS AND ANNOUNCEMENTS

Mond Nickel Fellowships

THE Mond Nickel Fellowships Committee now invites applications for the award of Mond Nickel Fellowships for the year 1952. Awards will be made to selected applicants of British nationality educated to University degree or similar standard, though not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments: they will normally take the form of travelling Fellowships—awards for training at Universities may be made in special circumstances. There are no age limits though awards will seldom be given to persons over 35 years of age. Each Fellowship will occupy one full working year. The Committee hope to award up to five Fellowships each year of an average value of £750 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects:—

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons qualified in Sciences other than Metallurgy may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications and previous career. Full particulars and forms of application can be obtained from The Secretary, Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1., to whom completed application forms must be returned not later than 1st June, 1952.

Fifth Empire Mining and Metallurgical Congress

THE Empire Council of Mining and Metallurgical Institutions announces that the Fifth Empire Mining and Metallurgical Congress will be held in Australia and New Zealand during April and May, 1953.

The chief object of the Congress is to afford an opportunity for mining engineers, metallurgists, engineers, and others concerned with the mining and metallurgical industries to meet and discuss technical progress and problems, including the mineral resources of the British Commonwealth of Nations. Anyone interested in the subjects to be discussed, irrespective of nationality, may apply for membership of the Congress.

The principal technical sessions will take place in Melbourne and Sydney, and there will be a series of visits to various mining areas of Australia and New Zealand. Copies of a circular giving preliminary details may be obtained from the Secretary, The Institution of Mining and Metallurgy, Salisbury House, Finsbury Circus, London, E.C.2.

Magnesium Advisory Committee

THE principal Companies of the U.K. magnesium industry have formed a consultative and advisory body to be known as the Magnesium Advisory Committee (M.A.C.), whose broad objective will be to encourage expansion in the production and applications of magnesium and its alloys. Initial activities will be to hold regular discussions on general policy and technical matters as between the member Companies, and to serve as the official liaison body for negotiations with the Ministry of Supply, Ministry of Materials and other Government Departments on all related subjects, at present with particular reference to the Defence Programme.

Membership is open to all Companies engaged in the production, casting and/or hot working of magnesium or its alloys, with the provision of approval of applications by the Committee. Founder Members of the M.A.C. are: Aeroplane and Motor Aluminium Castings, Ltd.; Birmetals, Ltd.; Birmingham Aluminium Casting (1903) Co., Ltd.; James Booth & Co., Ltd.; Bristol Aeroplane Co., Ltd.; High Duty Alloys, Ltd.; Kent Alloys, Ltd.; Magnesium Castings and Products, Ltd.; Magnesium Elektron, Ltd.; Rolls-Royce, Ltd.; Sterling Metals, Ltd.; J. Stone & Co. (Charlton), Ltd.; and Stone-Fry Magnesium, Ltd.

Meetings are for the present being held at Distillers House, St. James's Square, London, S.W.1., and Mr. R. G. Wilkinson, Deputy Chief Metallurgist, Magnesium Elektron. Ltd,, Bath House, 82, Piccadilly, London, W.1., is acting as Honorary Secretary, to whom all communications should be addressed.

Magnesium alloys are the lightest metallic materials in use to-day, being only two-thirds the weight of aluminium alloys, and magnesium is the only non-ferrous metal which is extracted in quantity from entirely domestic materials. In alloy form, both cast and wrought, it is of vital importance to the Defence Programme, since it is used extensively in aircraft, jet and propeller turbine engines and in many commercial fields.

Underground Nickel Mining Output Increased

THE International Nickel Company of Canada, Limited, mined more ore from underground in 1951 than in any year in its history. Production of ore from underground in 1951 was 7,780,000 tons, an increase of 2,000,000 tons over that of the previous year. Total ore mined from both underground and surface operations was 11,800,000 tons, compared with 9,849,000 tons in 1950.

During 1951, emergency facilities were installed and put into operation several months ahead of schedule, bringing the Company's rate of nickel production to 21,000,000 pounds per month, an increase of 5% over

the rate prevailing prior to mid-year. Sales of nickel, nickel alloys, copper, platinum and other products in 1951 are estimated at $286,700,000 (in terms of U.S. currency) compared with $228,071,346 in 1950.

While engaged in maximum production, International Nickel also pushed towards completion its extensive underground development programme initiated during World War II. By the end of 1953, when production from surface operations will be fully replaced, the Company will be able to hoist 13,000,000 tons of ore a year, which is twice as much from underground as in any year prior to 1951.

Sheet and Strip Metal Users' Technical Association

THE Spring Meeting of the Sheet and Strip Metal Users' Technical Association will be held at the Charing Cross Hotel, London, on Thursday, 3rd April, 1952, at 6-45 p.m. when a paper on "The Finishing of Motor Car Bodies" will be read by Mr. A. A. B. Harvey (Briggs Motor Bodies, Ltd.). The evening technical session will be preceded by two afternoon works visits, one to Briggs Motor Bodies, Ltd., Dagenham, and the other to the A.P.V. Co. Ltd., Wandsworth.

Institute of Metal Finishing

THE 1952 Spring Conference of the Institute of Metal Finishing will be held at the Grand Hotel, Eastbourne, from Wednesday, 23rd April to Saturday, 26th April, 1952. There will be five technical sessions in all, each dealing with a group of papers, the topics covered including Polishing, New Metal Finishing Techniques, Practical Plating Subjects, The Structure of Electrodeposits, and Beating the Nickel Shortage.

Zinc-Rich Paints

THE Corrosion Committee of the British Iron and Steel Research Association has issued the following statement about zinc-rich paints :—

> "The use of the term 'zinc-rich paint' should be restricted to paints containing a sufficiently high percentage of zinc pigment to ensure direct electronic contact between the metallic particles in the dry paint film. There are theoretical reasons for believing that in the simplest case this will not occur unless the metallic zinc constitutes 92/95% by weight of the dried paint film—the exact value depending on the specific gravity and other properties of the vehicle."

The Corrosion Committee sponsored the work at the Cambridge University Metallurgical Laboratories which, during the early years of the last war, led Dr. Evans and Dr. Mayne to establish the usefulness of such paints in resisting corrosion, and the form in which they can be most effective. Zinc-rich paints are now finding numerous domestic and industrial applications.

Foundry Article Competition

IN the current issue of their journal *Foundry Practice*, Foundry Services Ltd. announce a Short Article Competition. Articles about 400 words in length, on any aspect of foundry work, are invited, and competitors may submit any number of articles. Entries will be judged by a panel of well-known foundry personalities, and money prizes ranging from £15 to £5 will be awarded together with six consolation prizes in the form of books. Full details are available from Foundry Services Ltd., Nechells, Birmingham, 7. Closing date: 21st April, 1952.

Personal News

MR. F. W. BRUCE has been appointed Managing Director of Northern Aluminium Co. Ltd. in succession to MR. K. HALL who has accepted an appointment in the Head Office of the Aluminium Limited Group of Companies in Montreal, and whose resignation as Managing Director will take effect upon his departure for Canada.

MR. L. E. MEEKS and MR. H. R. WALTON, both previously Directors of Electroflo Meters Co. Ltd., have recently joined Elliott Brothers (London) Ltd. Mr. Meeks is closely identified with the production and design sides of the Elliott organisation, while Mr. Walton has taken charge of sales of the products of the Elliott subsidiary, Fisher Governor Co. Ltd.

MR. A. B. GRAHAM, Manager of the Zenith Works of Henry Wiggin & Co. Ltd. at Thornliebank, Glasgow, has been elected to the Delegate Board of the Company.

MR. A. C. ELLIS has been appointed Manager of the Cardiff Office of the Metropolitan-Vickers Electrical Co. Ltd. in succession to the late Mr. H. Coope.

MR. W. G. HOLMES retired at the end of last month after 38 years as Manager of the Southampton Branch of British Insulated Callenders' Cables Ltd. and the former Callender's Cable & Construction Co. Ltd. He is succeeded by MR. E. HITCHIN.

MR. R. DEAN ROBERTS has recently taken up an appointment as Director of Personnel for The David Brown Companies. Mr. Dean Roberts was formerly Personnel Manager at the Dagenham plant of the Ford Organisation.

Obituary

WE record with regret the deaths of the following :—

MR. T. A. M. ROBERTS, Sales Director of the Metals Division of Imperial Chemical Industries Ltd., who died suddenly on February 3rd at the age of 51. At the time of his death he was Chairman of the Brass and Copper Tube Association and the Extruded Brass and Copper Alloys Association, and had held executive and advisory offices in the Cold Rolled Brass and Copper Association, the High Conductivity Copper Association, and the Brass Wire Association. He was also a prominent member of the executive committee of the British Non-Ferrous Metals Federation.

MR. G. A. SCOTT who died at his home in Hendon on February 27th at the age of 58. For 32 years, Mr. Scott was in the service of The Wellman Smith Owen Engineering Corporation Ltd. as an Engineer in the Furnace Construction Department.

MR. G. S. PRESTON, M.B.E., Superintendent of the Metal Finishing Department of The Plessey Co. Ltd., who died on February 23rd at Ongar, at the age of 59.

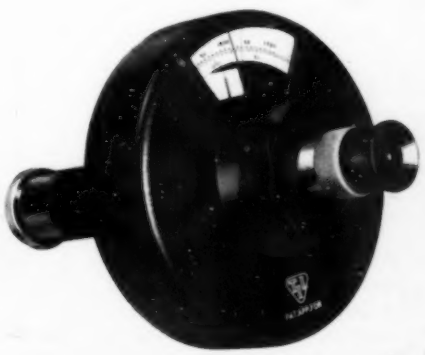
MR. GORDON H. FIELD, C.B.E., formerly Director of Research at Aluminium Laboratories, Banbury, who died on February 3rd.

MR. P. C. POPE, formerly Secretary of The Institute of Fuel, who died suddenly on March 1st, at the age of 80.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

High Precision Disappearing Filament Optical Pyrometer

ATTENTION was drawn to the limitations in precision of current British and foreign types of portable disappearing filament optical pyrometer in a paper by C. R. Barber* of the National Physical Laboratory in 1945. These were due to several major factors, amongst which are the designs of the pyrometer lamps, the designs of the optical systems, and the use of deflection instruments to indicate the lamp current or voltage, and hence the temperature. As a consequence of the publication of this paper, a high precision disappearing filament optical pyrometer was designed by the National Physical Laboratory in conjunction with the British Iron and Steel Research Association, and has been further developed and is manufactured under licence by Tinsley (Industrial Instruments) Ltd.



The pyrometer as illustrated here is self-contained except for the small dry battery which can be conveniently carried in a pocket. The body is of light alloy with a high quality and durable anodised black finish. The front extension tube, which supports the objective lens, provides a comfortable handle. The battery switch is arranged so that it can be operated by the gripping hand with the minimum of movement. A balanced bridge circuit measures the resistance of the comparison filament and hence indicates its brightness temperature with great accuracy. The bridge current rheostat and potentiometer balancing arm are adjusted by a single knob, and interlocking keys are provided to prevent accidental over-loading of the galvanometer.

The optical system comprises a simple telescope with the proper entrance and exit angles to ensure a bright field and good disappearance of the filament when a brightness match is made. A neutral filter is inserted in the optical system when the higher of the two ranges, 800–1,200° C. and 1,100–1,900° C., is required. Monochromatic vision is provided by a carefully selected colour filter. The lamp has a flat tungsten filament of very small thermal inertia and of sufficient length to eliminate ambient temperature errors resulting from end effects.

The pyrometers are normally calibrated against an N.P.L. sub-standard filament and a certificate of calibration stating the corrections is issued with each instrument. An N.P.L. certificate of calibration will be supplied if required.

*Tinsley (Industrial Instruments) Ltd., North Circular Road, West Twyford, London, N.W.*10.

* *J. Iron and Steel Inst.*, 1945, **152**, 171.

Pneumatically-operated Motor Butterfly Valves

To meet the need for pneumatically operated valves for the control of liquids and gases under relatively low static pressures, Fisher Governor Company, Ltd., have added a range of butterfly valves to the series of ported valves, pressure regulators and other specialities for automatic control, now made by the Company in England.

Fisher Butterfly Valves are available in sizes from 4 in. to 24 in. and control the flow of fluid by a disc on a rotary shaft linked in a simple manner to a pneumatically-operated diaphragm motor of the same type

as is used on the well known Fisher ported valves. The discs are shaped and ribbed for maximum strength and offer minimum resistance to fluid flow. In the closed position, the clearance area between the disc and body does not exceed 0·5% of the total pipe area. By the use

of a rugged crank and lever with accurately ground pins, lost motion in the operating mechanism is reduced to a negligible amount whilst reliability is ensured. Standard diaphragm pressure range is 3–15 lb./sq.in. and for automatic pressure regulation, the Fisher Wizard pilot can be mounted integral with the diaphragm casing. The Fisher Positrol valve positioner can also be fitted if required.

Typical applications for these valves are for coal and producer gases for the gas industry, for large low-pressure gas lines in steel works, oil refineries and chemical plants and low-pressure exhaust steam controls.

*Fisher Governor Company, Ltd., Century Works, Lewisham, London, S.E.*13.

Improved Electrical Resistance Alloy

FURTHER information is now available about the new nickel-chromium alloy, Karma, with a high resistivity and a low and stable temperature coefficient, recently announced by British Driver-Harris Co., Ltd., of Manchester.

It has extremely interesting possibilities in resistor manufacture, the higher ohmic values—resistivity of 800 ohms per circular mil-foot, and temperature coefficient of ± 0·00002 per deg. C. from — 50° C. to 100° C.—making it possible for even smaller precision resistors to be wound at a still lower cost per ohm. The more stable resistance of the alloy permits wider applications at extended temperature ranges; its low thermal E.M.F. value, compared with copper-base alloys, gives an assurance of extreme accuracy; and its superior resistance to oxidation prolongs its electrical properties. Furthermore, faster winding speeds are made possible by its higher tensile strength, while its lower thermal expansion minimises distortion and movement in windings.

Karma can be soldered, brazed or welded, and arrangements are being made to supply it with the conventional insulations, such as enamel and fabric coverings. It is available in wire sizes down to 0·001 in. diameter.

The manufacturers invite anyone interested to communicate with their Technical Department.

British Driver-Harris Co., Ltd., Manchester.

New Instron Tensile Tester Accessories

SEVERAL new accessories have been added to the precision, electronic Instron tensile tester, thereby increasing the versatility of this instrument which has found wide use in a number of fields. An auxiliary and easily removable crosshead compression accessory has been added, and this is attached to the frame below the moving crosshead. Compression type load cells have a rigidly attached load sensitive table and the sample is compressed between this table and the moving crosshead. The same flexibility of control for operating the motion of the crosshead in tensile measurements, is now possible for compression testing. Load deformation, cyclic, and relaxation data, can be obtained with the same accuracy and high speed response. By the use of simple jigs and fixtures, torsion and flexural measurements may be carried out to evaluate more completely the mechanical properties of the test specimen. The full scale range of compression tests available, with three interchangeable load cells, extends from 20 g. to 5,000 lb. This wide full-scale range is an outstanding feature of the instrument.

An integrator has also been developed with which, when applied to the Instron tester, the area under the load deformation curve equivalent to the energy either absorbed or returned by the test sample is immediately available from counter readings.

This machine provides a wide selection of jaw speeds ranging from 0·02 to 20 in. per min.; the combination of a versatile system for changing the load sensitivity and push-button switching for operating the moving crosshead, making available fast routine measurements as well as more complex testing techniques.

Instron Engineering Corporation, 2, Hancock Street, Quincy 71, *Mass., U.S.A.*

New Grades of Hard Metal

METRO-CUTANIT, LTD., announce that they are extending their range of "Cutanit" cemented carbide hard metals by beginning the manufacture of new grades containing tantalum and niobium carbides. The addition of these carbides to hard metals of the tungsten carbide–titanium carbide–cobalt type gives increased hot hardness and toughness, hence improved cutting properties and tool life. This represents a great step forward in the quality of hard metal available in this country. Tool tips will shortly be available through "Cutanit" distributors—William Jessop and Sons, Ltd., Sheffield. Amongst the first to be produced will be a universal grade "U," suitable for machining both steel and cast iron.

Liquid Honing to the Trade

UNTIL recently it was considered that the new finishing process of liquid honing was a luxury of use to some specialised industries only, but now it is realised that its advantages may be of value in a wide range of industries. It can be used for such varied purposes as cleaning and preparation of dies to improve casting surfaces, descaling of rod prior to drawing, removal of hardening scale and grinding marks, and the finishing of aero-engine cylinder bores. The finish obtainable can be superior to that of stone honing and, if required, dimensional tolerances of 0·0002 in. are obtainable.

In order to meet the demand for the liquid honing of parts by firms whose volume of work is not sufficient to warrant the installation of their own plant, a new company, Intermetric Processes Ltd., has been formed with headquarters at Darby Road, Coalbrookdale, Shropshire.

Tonnage Ozone Equipment

E.C.D. LTD. announce that arrangements have been made for them to manufacture and sell under an exclusive licence in Great Britain, and on a non-exclusive basis in certain other territories, the Tonnage Ozone Equipment of the Welsbach International, Inc. of Philadelphia, U.S.A.

Change of Name

INTERNATIONAL TIME RECORDING CO., LTD., has changed its name to I.R.M. United Kingdom, Ltd., as this title is more representative of the expansion of its business, which now includes a wide range of International business machines, such as electric accounting machines and electric typewriters, as well as time recording, time indicating and time signalling equipment and ticketographs.

CURRENT LITERATURE

Book Notices

Electrolytic Polishing and Bright Plating of Metals

By S. Wernick, with Foreword by Ulick R. Evans. Published by Alvin Redman, Ltd., 4, Fitzroy Street, Fitzroy Square, London, W.1. 8½ × 5½ in., 244 pages, 69 illustrations. Price 30s.

In the past, good design has largely been taken to mean satisfactory functional qualities in use combined with pleasing lines, but to-day there is a growing realisation that, in addition to the importance of quality of material and workmanship, the quality of finish cannot be over-emphasised. Apart from improved appearance, the life of an article is often dependent on the finish and a bad finish too often means fewer repeat export orders. Manufacturers, generally, are aware of this fact and, in consequence, electroplating processes have never been in such demand. Until comparatively recently, these processes comprised the deposition process, based on electro-chemical principles, and the polishing process, based purely on mechanical principles. Mechanical polishing has many disadvantages and, as a result of intensive laboratory research, electro-chemical methods have been developed to by-pass this operation.

Two methods have been developed, the first by means of bright plating solutions, which deposit a highly lustrous metallic coating that needs no subsequent polishing, and the second, which bids fair to be more important than the first, is the electrolytic polishing of metals, which completely eliminates the costly mechanical method. A factual account of these two developments is presented in this book and the author is particularly well fitted to deal with them.

This book is a second edition—the first having been published in 1948—and this fact indicates its popularity in the metal finishing industry. In his initial chapter on the development of electrolytic polishing the author briefly describes the history of the process. However long ago the first observation was made of the electrolytic polishing action—and the author considers it more probable that some plater in the shop observed the phenomenon but did not think it worthy of recording—no reference appears to have been chronicled before 1925, but the very important work of Jacquet, from 1935 onwards, pointed the road leading to the production of polished surfaces for industrial purposes.

The author deals informatively with the electrolytic polishing of stainless steels, nickel, aluminium, carbon steels, copper and silver, and devotes a chapter to the industrial applications of electrolytic polishing to non-ferrous metals. He describes various processes which have been developed and considers they have gone a long way towards perfecting a major application of electro-polishing, and its possible incorporation into a continuous plating cycle without intermediate mechanical operations.

In the bright plating process, the material applied usually possesses a different composition from that applied during an ordinary plating process, owing to the incorporation of a brightening agent, and sometimes the co-deposition of a second metal. Dr. Wernick wastes no time in getting down to the subject and describes bright plating in nickel, zinc and cadmium, copper and silver. In two separate chapters he also describes the deposition of platinum and palladium, and of rhodium. A useful Appendix deals with the development of bright nickel plating in America and an extensive and valuable bibliography is given. To all connected with the metal finishing industries this book will be invaluable.

W.A.

Copper : Its Ores, Mining and Extraction

Published by the Copper Development Association, Kendals Hall, Radlett, Herts. 48 pp., 36 illustrations. No charge.

In response to many requests from teachers in technical schools, science masters, and students generally, this booklet has been prepared by the Copper Development Association in order to explain briefly and simply how commercial copper is derived from the original ore by mining, dressing, smelting, refining and fabricating. The distribution of copper ores in the principal producing countries of the world is indicated on a map, and numerous photographs and diagrams which accompany the text take the reader through the various steps from the mining of the ore to the smelting and refining processes which yield copper of high purity for commercial use.

Trade Publications

The latest issue of "Tin and its Uses" (No. 25) appears in a cover of new and bold design and contains a number of short articles dealing with progress in the main fields of tin usage. Reference is made to a new pewter alloy, developed in the Tin Research Institute's metallurgical laboratory, which can be spun in a soft condition and subsequently hardened by heat-treatment so that it retains its shape in use. Other articles deal with the success which has been attained in the reduction, by tin-zinc plating, of the corrosion of steel bolts fixed in aluminium structures, and the use of tin-nickel electroplate which is being taken up in several countries, including the United States. Of general interest are the sections dealing with early tin and bronze coins, the expansion of tinplate production and the grim conditions under which tin-mining has lately been carried out in Malaya.

A cleverly designed metals weight calculator for quickly determining the weights of sheet and plate, wire, rod, and bar, in addition to small round wire, tubing, and sheet and plate circles is being offered by the Reynolds Metals Company. Printed on both sides with two sliding indicators, the sturdy, 2-colour computer is 8¾ in. × 3 in. in size. Each calculator is supplied with a folder of instructions which, in a few words, clearly show the operation by giving examples of the various kinds of computable problems. Lengths may be determined from weights by changing the order of the settings, and further familiarity with the instrument

will suggest other types of problems which can be solved. Included on the calculator is a chart of decimal equivalents for quick reference. The Reynolds Metals Calculator will be sent without charge upon request (on company letterhead) to Export Division, Reynolds Metals Company, 19 East 47th Street, New York 17, New York.

Following the successful introduction of their Pipe Welding and Pipe Welding (Molybdenum Bearing) electrodes, The Quasi-Arc Company Ltd. have now issued an eight-page technical circular giving details of the mechanical properties and chemical composition, welding technique, deposition and packing data, as well as the applications and characteristics of the electrodes. Copies of this new technical circular can be obtained from The Quasi-Arc Company Ltd., Bilston, Staffordshire.

Recent alterations to many British and American specification numbers for aluminium casting alloys have necessitated a revision of the Alar Data Sheet: "Cast Aluminium Alloys—Related Specifications and Trade Names," which was first published in 1949. Copies may be obtained from Alar Ltd., 3, Albemarle Street, London, W.1.

The current issue of Wiggin Nickel Alloys contains a description of the new Rover light-weight gas turbine, in which Nimonic alloys are employed, and articles on wire cloth manufacture, chemical valves and the mag-nickel fuse. An interesting inclusion is a photograph of a model made to celebrate the discovery of nickel two hundred years ago. This model was seen by thousands at the Engineering Exhibition last September and then flown to Detroit where it was one of the attractions at The World Metallurgical Congress in the following month. Copies may be obtained on application to Messrs. Henry Wiggin & Co. Ltd., Wiggin Street, Birmingham, 16.

A new Croda leaflet introduces Crocell plastic coating which is used for the protection of finished components or precision tools from corrosion and mechanical damage during storage and transit. It is applied by dipping the component in molten Crocell at 160°–185° C. When necessary, the skin is removed by slitting open when it comes away in one piece leaving a film of lubricating oil, exuded by the film during storage. Copies of the leaflet may be obtained from Croda Ltd., Croda House, Snaith, Goole, Yorks.

Believed to be the first of its kind, an instruction manual on the care and maintenance of P.V.C. gloves and clothing has recently been published by James North and Sons Ltd., Hyde. Copies may be obtained free of charge from Northide Ltd., distributors of North P.V.C. clothing, of Queen Street, Stockport, Cheshire. Besides details of methods of putting on and removing protective clothing, cleaning and maintenance procedures, and storage facilities, extracts are given from the safety regulations operative in a number of trades.

We have received from Air Control Installations Ltd., Ruislip, Middlesex, a copy of Publication G.512—"What We Make"—which provides an illustrated guide to the Company's products which include centrifugal and axial fans, small blowers, heating and cooling plant, air conditioning plant, drying plant, air filters, dust and fume control, humidifying plant, agricultural equipment and climatic test cabinets. Further details are given in Pub. R.514 of dust control by Rotoclone.

Birlec's latest 8-page publication, No. 81, deals with the use of controlled atmospheres in heat-treatment furnaces. In the main the publication concerns partially burnt town's gas atmospheres for which two types of generator have been developed—the "exothermic" type for high air-town's gas ratios, and the "endothermic" type (with external heating elements) for low ratios. Each type is described in some detail and a selection chart shows which type is recommended for the majority of common heat treatment applications. Brief reference is also made to charcoal generators and ammonia cracking plant. Copies of this publication may be obtained from the Publicity Dept., Birlec Ltd., Tyburn Road, Birmingham, 24.

For the smooth and efficient running of all types of machine, the design, durability, and lubrication of the bearings are all important factors. The contribution which 'Reservoil' oil retaining bearings can make to the solution of the twin problems of bearing failure and expensive lubrication is emphasized in a recent Morgan Crucible Company publication. The special porous structure of these bearings, made by powder metallurgy methods from bronze or iron powders enables them to hold up to 30% by volume of oil, which provides sufficient lubrication for all but the most severe conditions of load, speed, and temperature.

Books Received

"Thermodynamics of Alloys," by John Lumsden. Institute of Metals Monograph and Report Series No. 11. 384 pp. inc. tables and indices. London, 1952. Institute of Metals. 35s. ($5·50).

"Metallkunde," by Prof. Dr. Ing. habil. Heinz Borchers, I—"Aufbau der Metalle und Legierungen." 100 pp. inc. 2 tables and 90 illustrations. 2nd Edition. Berlin, 1950. Walter de Gruyter & Co. DM.2.40.

"Metallkunde," by Prof. Dr. Ing. habil Heinz Borchers, II—"Eigenschaften, Grundzüge der Formund Zustandsgebung." 154 pp. inc. 8 tables and 100 illustrations. 2nd Edition. Berlin, 1952. Walter de Gruyter & Co. DM. 2.40.

"Structural Adhesives" (Lectures given in Cambridge at the Summer School, "The Technology of Synthetic Resin Adhesives," held by Aero Research Ltd.). 203 pp. inc. index and numerous illustrations. London, 1951. Lange, Maxwell & Springer, Ltd. 21s.

"Défauts de Fonderie," by François Boussard. Foreword by Albert Portevin. 424 pp. inc. 139 illustrations and numerous tables. Paris, 1952. Dunod. 2,700 f.

"Industrial Furnaces." Fourth Edition. Vol. I. By W. Trinks. 526 pp. inc. numerous illustrations and index. New York and London, 1952. John Wiley & Sons, Inc., and Chapman & Hall Ltd. $10 or 80s. net.

"Chemical and Electroplated Finishes" by H. Silman. Foreword by Dr. H. Moore. 2nd Edition. 479 pp. inc. numerous illustrations and author and subject indices. London, 1952. Chapman & Hall Ltd. 50s. net.

"Elements of Ceramics" by F. H. Norton. 246 pp. inc. appendix, index, numerous illustrations and tables plus a table of symbols and units. Cambridge, Mass., 1952. Addison–Wesley Press, Inc. $6.50.

METALLURGICAL DIGEST

The Function of Energizers in Pack Carburizing

By Axel Hultgren

AFTER studying the various ways in which the energizers K_2CO_3, Na_2CO_3, and $BaCO_3$ may be placed in the carburizer box with crushed charcoal and the objects to be carburized, two methods are found to give the same results as mixing charcoal and energizer:

(1) K_2CO_3 or Na_2CO_3 applied separately; e.g., as a layer on top of the charcoal. These two energizers on being heated to the carburizing temperature rapidly spread out, forming a uniform mixture with the charcoal.

(2) $BaCO_3$, applied as a thin coating on the steel surface, preferably with the aid of a binding agent, such as lacquer. The coated specimens are packed in unmixed charcoal which has been washed thoroughly with dilute hydrochloric acid. As $BaCO_3$ has very small spreading power it remains where it is applied, exercising its energizing function near the steel surface; apparently, the presence of an energizer is not required beyond a certain small distance from this surface. In carrying out the carburizing process with $BaCO_3$-coated steel objects, the presence of a small amount of K_2CO_3 in the charcoal or in the coating may interfere with the carburizing reaction in some unknown manner, so leading to poor results.

When a carburizer is used repeatedly, it is necessary to mix a minimum quantity of fresh crushed charcoal, about 10% of the total charge, with the spent carburizer each time it is reused. A small amount of energizer should be added occasionally to compensate for the small evaporation and handling losses. When 33% of K_2CO_3 was originally added to a sample of charcoal, about 10% of fresh charcoal being admixed each time the test was repeated, 10% of K_2CO_3 added after ten runs maintained good carburization during the following ten runs with charcoal additions only. (If the energizer added is $BaCO_3$, it must be mixed with the carburizer.) Provided that the boxes are well sealed, the shrinkage of the carburizer in one carburizing operation may be so small that simply replenishing with charcoal will not satisfy the above condition of a minimum addition: if so, the steel objects are required to be more closely packed, thus increasing the ratio of steel surface to carburizer volume.

The decline in carburizing power of a powerful carburizer used repeatedly without any additions, noticeable after two or three carburizing cycles, is probably caused by a rapid loss in active surface area of the charcoal particles, and certainly not by loss of energizer.

An 1:1 N_2-CO_2 mixture was passed, at 925° C., at fixed rates of flow through a layer of charcoal or graphite, unmixed or with additions of KOH or BaO. It was found that unmixed charcoal reacted slowly with CO_2 while a low CO_2 concentration in the exit gas, approximately that of equilibrium with carbon, was obtained on adding KOH to charcoal or graphite at a flow rate of 0·5 l/min. and also on adding BaO to charcoal at 0·006 l/min. On adding BaO to graphite at 0·002 l/min. the CO_2 concentration obtained was somewhat higher than the equilibrium value.

Hence it may be concluded that energizers in carburizing compounds act as catalyzers for the reaction $CO_2 + C = 2\ CO$. In this way a high CO concentration is maintained near the steel surface and carburization is accelerated.

From *Jernkontorets Annaler*, 1951, **135**, 575–604.

New Lithium Ceramics

By R. E. Stark and B. H. Dilks, Jnr.

A SERIES of new ceramic materials having a coefficient of thermal expansion that can be controlled by formulation of the ceramic, and having excellent resistance to thermal shock, has been announced. The new ceramics are based upon lithium alumino-silicate.

In addition to high resistance to thermal shock, a low coefficient of expansion is important for applications in which the materials are required to hold dimensions through a wide range of temperatures. Various compositions in the series can be produced with properties so controlled as to provide a range of coefficients of thermal expansion, from positive to negative. The ceramics are produced from blends of lithium-bearing minerals and clay or blends of other ceramic materials to obtain the desired ratio of lithia, alumina and silica.

Research work that led to the production of the commercial material was carried out by Floyd A. Hummel and described in 1948. Lithium alumino-silicate compositions were studied as offering several desirable properties. Later development of this research showed that a range of compositions could be produced in which silica content was varied to provide a range of coefficients of thermal expansion. A practical upper limit to the amount of silica is reached at a point where free silica is present and undergoes a phase change upon heating or cooling through a critical temperature, rendering it useless as a thermal shock-resisting material. At the other extreme of the practical range, a composition with negative coefficient of expansion—that is, one that contracts upon heating—is found. The series of useful compositions runs from those having a very low expansivity to those having a very large contraction upon heating. Thus, in the series are compositions on the silica side having a thermal expansion coefficient of 2×10^{-6} in./in./deg. C. in the range of 70 to 950° F. At the other extreme of the series are compositions with a coefficient of thermal expansion of $-6{\cdot}25 \times 10^{-6}$ in./in./deg. C.

All testing done seems to show that the lithium ceramics will remain stable indefinitely at high temperatures. Samples held at 2,000° F. for periods of 30, 60, 90 and 120 days showed no perceptible change in specific gravity

From *Materials and Methods*, **35** (1952), 99-100.

or other properties. They have excellent chemical stability at temperatures below 1,800° F., but will react with some material at higher temperatures. Suitable washes can be used to give protection at temperatures above 1,800° F. The excellent resistance of these ceramics was illustrated in the laboratory by heating specimens to 2,000° F. and dropping them into liquid air. This treatment was repeated 100 times without ill effect.

Silicon Carbide as Alternative to Special Service Alloys

By John L. Everhart

IN view of possible shortages of high temperature alloys, an alternative material is silicon carbide. Used as a substitute for heat-resisting alloys during the recent world war, bonded silicon carbide proved so satisfactory in several applications that it displaced the metal permanently. In cost it compares favourably with stainless steel.

When shaped into a brick or other form with suitable bonding agents, silicon carbide has a number of properties which are unusual in a material thought of primarily as a refractory or an abrasive. Among these properties are strength, thermal conductivity, abrasion resistance and corrosion resistance. Silicon carbide refractories retain strength and rigidity at temperatures over 1,540° C. while the heat-resisting steels weaken rapidly above 945° C.

Perhaps one of the best examples of an application requiring resistance to heat is the liner and throat of an uncooled rocket motor. These liners, in which the fuel is burned, and the throats through which the propellent gases are expelled must withstand high temperatures and severe erosion. Large rocket motors may burn four tons of fuel in 75 sec., with an estimated temperature in the throat of 3,000° C. If a metal will withstand these severe requirements for 1¼ min. it is considered good. Special silicon carbide refractories have withstood the same conditions many times as long as the metals in some units.

Applications based primarily on resistance to heat include fixtures to hold parts for high temperature brazing. Metal supports in a production operation in which the parts to be brazed were heated in an atmosphere furnace on a cycle from cold to 1,150° C. to cold in 1½ hrs. warped badly. When the metal holders were replaced with silicon carbide shapes, the life was doubled and sticking of brazing material to the fixture was eliminated. In many forging and heat treatment operations, special furnace atmospheres have become necessary, and an economical means of generating the gases has been needed. Furnace builders now offer suitable generators as an integral part of their equipment. In these tube-type generators, sulphur in the fuel is corrosive to the chromium-nickel alloys which have been used for tubes, and silicon carbide cylinders have been substituted in many cases with complete success.

For the lining of retorts used in the reduction of a number of substances, silicon carbide refractories have proved more satisfactory than heat-resisting alloys. Typical examples of such applications are the winning of zinc and other metals from their ores.

Other applications based primarily on the strength at elevated temperatures, and the high thermal conductivity, are muffles and radiant tube heaters. In addition to their good thermal conductivities, silicon carbide refractories offer the advantages of greater emissivities and rates of heat absorption.

The high resistance to abrasion of silicon carbide refractories is the foundation of a number of applications, including skid rails, linings for cyclone dust collectors, and impellers for centrifugal pumps. An application of silicon carbide shapes for moving parts is illustrated by the use of this material in roller hearth furnaces for handling sheet and similar products. Many of these furnaces are equipped with water-cooled rollers. With this arrangement the roll surface, being much cooler than the furnace, can produce black spots on the sheets. Other furnaces are equipped with air-cooled alloy steel rolls. These may weld momentarily to the sheet, causing surface blemishes, while warping of the rolls can result in unequal annealing. To overcome these sources of defects, mills frequently resort to rider sheets to carry the work through the furnace and preserve the finish. Some mills have replaced metal rollers of both types with silicon carbide jacketed rollers. These consist of a water-cooled steel shaft covered with an insulating material outside of which the silicon carbide roller is mounted. Uncooled silicon carbide rollers are also in service.

These and other applications cited by the author indicate the possibilities of using silicon carbide for service involving resistance to heat, abrasion, of corrosion.

From *Materials and Methods*, **34**, (Nov., 1951), 71–75.

Briquetting Copper Ore Concentrates

THE use of a briquetting process, instead of sintering, for the preparation of copper ore concentrates prior to charging into the blast furnace was tried out in France, but without much success. Another experiment has been carried out recently by Mr. H. Mehailovitch at the Bor mines in Yugoslavia, and the results are reported to be most encouraging. As the calorific value of the sulphur is no longer lost but put to useful work in the blast furnace, coke consumption was about 30% lower than when smelting concentrates sintered in the usual way, and a further reduction is expected to be achieved by briquetting some coal with the concentrate. Dust in the blast furnace gases was reduced, contrary to expectations, by as much as 65%. Furthermore, considerable latitude in blast furnace operating conditions was found to be permissible when smelting briquetted ore.

The gypsum used as a binder in briquetting is obtained by neutralising spent copper sulphate liquor by additions of lime. This liquor, from which part of the copper has been recovered, contains free sulphuric acid and the remainder of the copper sulphate, which was not previously recoverable. At the same time as the sulphuric acid is being neutralised, the remaining copper sulphate is converted into hydroxide which passes, together with the gypsum, into the briquettes, to be reduced finally in the blast furnace. Copper recovery from the liquor, which had previously gone to waste when spent, will therefore, increase from 50% to 99%.

From *Xia* (Belgrade), Dec. 16th, 1951.

LABORATORY METHODS

MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

MARCH, 1952 Vol. XLV, No. 269

The Determination of Local Wear by the Use of Disappearing Marks

It is possible to measure the wear of a metal by noting the change in dimensions of a depression in the surface concerned. Various methods of making the depression are considered and their relative merits discussed.

AMONG the many methods of measuring wear on metals, are a number based on the measurement of the size, before and after wear, of a depression in the surface. A procedure using "cut lunes" has been described in the Russian technical press, and a brief digest of the salient features is followed here by a commentary on similar methods of wear measurement.

Wear Measurement by Cut Lunes*

By M. M. KHRUSHCHOV and E. S. BERKOVICH

Methods for determining local wear have been described previously by one of the authors[1], and one of these methods, using indentation marks, has been studied during the last two years. An indentation is made on the test surface with a diamond pyramid, using a standard hardness tester, and the reduction in diagonal noted as wear proceeds. This method has serious drawbacks. In the first place, the surface round the indentation is raised above the general level, and the effect varies with different metals and alloys and with varying treatment. This raised lip is shown particularly well by multiple beam interferometry, and measurements have shown that the maximum height of bulging for some steels may be as much as 2·5% of the diagonal length. Wear at such a point is clearly greater than average, and special precautions must be taken to avoid errors arising. Secondly, the form of the indentation differs from that of the indenting diamond pyramid as, owing to 'elastic recovery,' the bottom of the indentation rises slightly after removal of the load, and the effect is proportionately greater than the reduction in diagonal length from a similar recovery. It is necessary, therefore, to determine the ratio $n = \triangle d / \triangle h$ for a given material. With a standard diamond pyramid, $n = 7{\cdot}0$; for cylinder cast iron it is about 10% greater, and for some tempered steels more than 25% greater. It will be seen, therefore, that the first of these drawbacks complicates the use of the method, whilst the second introduces errors in the results.

A further method which has been developed—and one which is free from the above mentioned drawbacks—is that of "cut-out lunes." A rotary V-shaped diamond tool[2] is used to cut, in one pass, a groove of about 1 mm. length. If the tip of the tool has a radius r, and l is the length of the cut, then h, the depth of cut will be approximately $l^2/8r$ and

$$\frac{dl}{dh} = \frac{8r}{2l} = \frac{l}{2h}$$

There is no bulging round the edge, as can be shown clearly by interferometry[3], and the depth is given with sufficient accuracy by the above formula. Nor is there any "elastic recovery" of the bottom of the cut, and repeated tests on the same steel have shown the advantage of this method over that using indentation. A basic feature of the "cut lune" method is the variation in rate of change of depth with length at different lengths, so that the amount of wear is determined by the difference in the calculated depths before and after test.

Neither "cut lune" nor indentation methods are recommended for highly stressed components working under variable loads, since the point of the cut or impression may act as a "stress raiser." Suitable equipment has been designed for "cut lune" tests on such varying components as flat surfaces, piston pins, automobile and tractor engine cylinders, etc.

Wear Testing by Disappearing Marks*

The idea of using "marks" in a surface for measuring wear by observing their progressive reduction in size is not new, but previously such marks have generally been produced by indentation and not by cutting-out methods.

Marks Produced by Indentation.[4]—This idea seems to have originated with Siemens–Schuckert of Berlin, who in German Patent 522,213, described the use of grooves of accurately determined size and shape made with a pointed tool. Later on, H. C. Dickinson and S. A. McKee in U.S. Patent 2,233,403 described a new instrument having a diamond point similar in shape to the Knoop indenter, but with different angles. Since there is a constant relationship between depth and length of indentation, the former can be calculated from the latter. The proposed wear gauge consisted of four parts: (1) an indenter for putting the mark on the

* *Doklady Akad Nauk*, 73, 1950, 909-910.
1 M. M. Khrushchov. Friction and Wear in Machines, Sborn III, pub. AN. SSSR. 1948.

* Comments by P. Grodzinski, Industrial Diamond Information Bureau.
2 The included angle and the shape of the diamond tool used are not stated.
3 The illustrations of the original article cannot be satisfactorily reproduced from the photostats available.
4 *Ind. Diamond Rev.*, 4, 1944, 151.

Fig. 1.—Flexible-shaft-driven hand equipment for making micro-cuts of variable depth using a double cone diamond-impregnated sintered carbide wheel.

testpiece; (2) a measuring microscope; (3) a cylinder indentation locater; and (4) a polishing template, for lightly polishing the surface after indentation. The last item reveals a serious defect in this method, namely, the bulging of the material round the indentation. This bulging cannot be prevented if the indentation method described is used.

Marks Produced by Abrasion.—In the Dickinson and McKee patent, it is also stated that the mark can be produced by abrasion. Some years ago the writer had the idea of applying his micro-abrasion method (Brit. Pat. 665,429; German Pat. 859,512; U.S. Pat. applied for) for this purpose, but evidently the above specification would not permit the making of a substantiated claim. In the micro-abrasion tester, a small wheel of 1 in. or less in diameter rotates at high speed (between 10,000 and 20,000 r.p.m.) and with diamond abrasive, either in the loose or bonded form, small cuts of 1 to 2 mm. length can be made in less than 15 seconds in the surface of any hard material, including those of Mohs' hardness values above 9, and even in diamond itself.

In the original micro-abrasion tester, only relatively small samples (about 1 in. diameter and $\frac{1}{2}$ in. deep) could be held, and hand equipment has, therefore, been developed with which micro-marks of a fixed depth can be produced (Fig. 1). The equipment is driven by flexible shaft, or it can be fixed to a high-speed electric hand motor. The spindle carrying the abrasive wheel of double conical shape is held between two conical fibre bearings; a wire loop serves as a flexible coupling. A hinged plate, of adjustable inclination and pivoted in a direction parallel to the axis of the spindle, is under spring pressure which pushes it away from a fixed stop, whilst the displacement of the plate is indicated on a small dial gauge. The grinding wheel can project through the centre of the plate and in this way the depth of cut can be closely controlled. The upper part of the housing is formed as a handle and when pressure is applied to the handle, a mark of adjusted depth is made.

Fig. 2 (× 25) shows two abrasion marks produced with a double conical grinding wheel on a cylindrical face of a specimen of sintered carbide. The test face was ground on the periphery of a 4-in. diameter diamond-charged cast iron drum before the marks were made, and after "marking," grinding on the drum was continued. Fig. 3 (× 25) shows the specimen after about 3 minutes further grinding; one mark has disappeared and the other has become smaller, and from the difference in length, the difference in depth may be calculated. Generally, the depth of a mark is approximately $h = l^2/8r$; where l is the length of the mark and r the radius of the double conical grinding wheel ($r = \frac{1}{2}$ in.). The thickness of the layer removed

$$d = h_1 - h_2 = (l_1^2 - l_2^2)/8r,$$

where l_1 and l_2 are the lengths of the mark before and after re-grinding. In this case, a layer of 0·018 mm. thickness (weighing about 3·7 mg.) was removed, thus making the smaller mark of 0·013 mm. depth disappear. In principle, it does not matter whether "wear" is due to a few minutes' grinding operation or to long use, for example, in a journal bearing.

Marks Produced by Cutting.—In the cutting method, a single-point tool[5] is used and the abrasive wheel of the micro-abrasion tester replaced by a fly-cutter. The abrasive wheel is fed by gravity load, but the fly-cutter needs a positive feed movement applied to the work carrier, for instance, by means of a screw-operated lever. In the abrasion test, the feed is constant and is deter-

5 This method was tried out about two years ago.

Fig. 2.—Micro-abrasion marks on sintered carbide. × 25

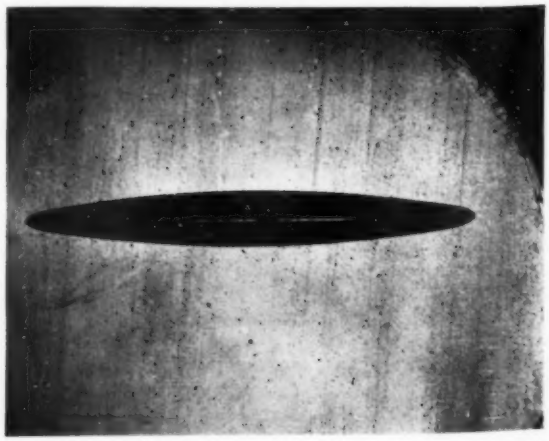


Fig. 3.—Same specimen as Fig. 2 after 3 minutes' further grinding. × 25

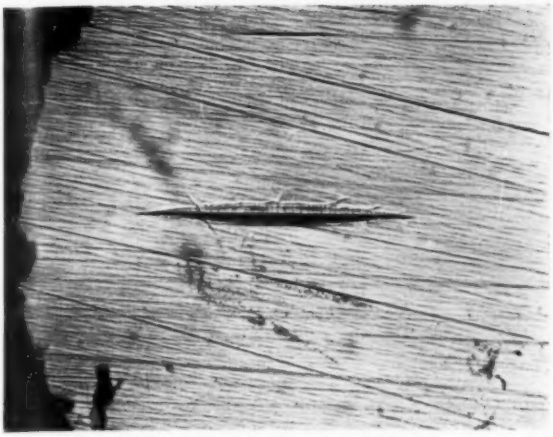


Fig. 4.—Fly-cutter mark on speculum. ×100

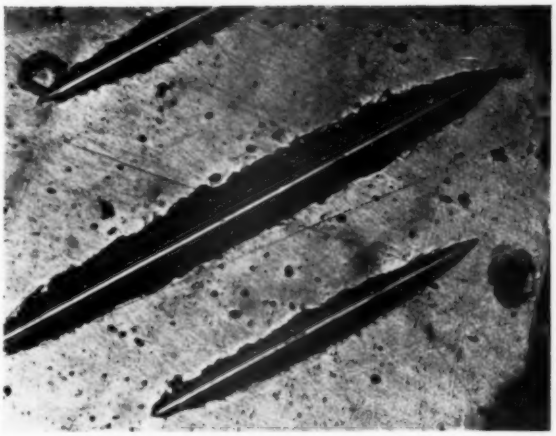


Fig. 5.—Fly-cutter marks on copper. ×100

mined by the weight applied, but in the cutting method control of the pressure is obviously impossible.

For the experiments, a shaped diamond tool with an included angle of 110° was used. The distance from the nose of the tool to the wheel centre of the fly-cutter was $r = 15{\cdot}1$ mm. The depth of a milling mark, therefore, of 1 mm. length was $d = 1^2/8r = 1/(8 \times 15{\cdot}1) = 0{\cdot}008$ mm. One turn of the lever micrometer screw raised the specimen by 0·16 mm., and when the specimen was fed into the fly-cutter by 1/20th of a turn of the screw, a milling mark of 1 mm. length and 0·008 mm. depth was produced. 1/16th of a turn of the screw produced a milling mark of 0·01 mm. depth.

By setting the lever attachment first, and rotating the fly-cutter afterwards, no great difficulties were encountered in producing marks of this size. The best marks in metal specimens were obtained when the fly-cutter was rotated by hand once over the specimen (about three-quarters of a wheel rotation). If at the same setting the motor is turned on for a fraction of a second, deeper and longer marks result, probably owing to vibration. Marks of 1 mm. length could also be made with the motor-driven fly-cutter, but the edges of the mark tended to be less "clear cut." The appearance of the marks was, however, sufficiently precise to enable exact measurements to be made.

Fig. 4 (× 100) shows a "cut" of about ½ mm. length produced by hand on speculum (brass or copper base), and Fig. 5 (× 100) shows marks on copper made by turning on the motor for as short a time as possible.

It is of interest to note that the Russian investigators have developed the marking method solely by cutting by using a diamond cutting tool operating at a radius of 10 mm. and producing marks of about 1 mm. length but the apparatus used has not been described. The cutting method, as also pointed out by the Russian investigators, is definitely limited to the testing of metals which are not too hard, so that many minerals, crystals and other hard and brittle materials cannot be tested by this method.

The abrasive wheel method, such as used by the author and also recently recommended by T. A. Jaggar (1950)[6], could probably be used in the Russian apparatus, but no mention of this rather more general method has been made.

6 T. A. Jaggar, Abrasion Hardness, 5th Special Report of the Hawaiian Volcano Observatory of the Hawaiian Volcano Res. Assoc. and the U.S. Geological Survey.

New British Chemical Standards

Bureau of Analysed Samples, Ltd., announce the following two new standard samples which are now available.

B.C.S. No. 247 *White Cast Iron*

Total Carbon	3·07%
Sulphur	0·186%

This sample has been specially prepared for the determination of total carbon and sulphur by combustion. In the absence of graphite, 80 mesh crushed material presents no difficulty regarding the distribution of carbon and is, therefore, specially recommended for daily routine checks put through a combustion furnace prior to carrying out determinations for total carbon or sulphur.

B.C.S. No. 246 *Nb–Mo* 18/8 *Stainless Steel*

Carbon	0·062%
Niobium	0·82%
Molybdenum	2·89%

This sample has been specially prepared for checking the determination of niobium in stainless steels and for accurate determinations of carbon in low-carbon stainless steels. It is also useful for checking the determination of molybdenum in high-molybdenum stainless steels.

As usual each standard sample is available in bottles of 25, 50, 100 and 500 grams and can be obtained through the usual laboratory furnishers or direct from Bureau of Analysed Samples Ltd., 234, Marton Road, Middlesbrough. Each bottle is provided with a Certificate giving the results of each Analyst and an outline of the method of analysis used for each element.

Correction

The Identification of Metals and Alloys by Spot Testing

We should be glad if readers would make the following corrections to page 104 of the February issue :

Column I, line 13, should read : "distinguishing between 7% chrome steel and lower and"

The materials in the fourth group in column I of the table are Hastelloy A (Wrought) and Nickel.

H.D.A. Central Laboratories Revisited

THE very name of High Duty Alloys, Ltd., suggests that the main purpose of the Company is the provision of materials capable of satisfying the highest demands of the designer. These demands are not fixed, however, but are continually increasing for, as progress continues to be made, to-day's high performance machines become the general standard of to-morrow, their place in the front rank being taken by something better. Small wonder, therefore, that H.D.A. have always held that the future of the light alloy industry is inseparable from research, and that the development of new techniques, together with the improvement of materials, must keep several moves ahead of the production departments and the immediate requirements of industry. This in turn necessitates a constant programme for the design of new and the improvement of existing equipment. Some years ago we presented in this journal a description of the H.D.A. Central Laboratories, but since then a considerable number of changes have, naturally, taken place, and in the following brief outline of the work of the Laboratories, reference is made to equipment which has been installed recently.

Chemical and Spectrographic Laboratories

A considerable amount of routine and special analysis is carried out in these laboratories to aid the research of other departments, and for this purpose gravimetric, volumetric, photometric, polarographic and spectrographic procedures are used. The work is not confined to the normal alloys, but covers a wide range of metallurgical, inorganic and organic analysis. There is also a regular programme for the manufacture and analysis of spectrographic standards for internal and external use, whilst the microchemical laboratory is available for the analysis of deposits and corrosion products and investigations into segregation. Research is always in progress with a view to improving existing methods of analysis and to developing new methods, especially for the more complex alloys and those containing the rarer elements. Chemical and spectrographic work is carried out in collaboration with outside organisations—e.g., British Standards Institution and the British Non-Ferrous Metals Research Association.

Cabinet lined with super-purity aluminium for salt-spray corrosion testing.

Corrosion and Surface Protection Laboratory

Two main methods of corrosion resistance testing are carried out :—

(*a*) Intermittent immersion in salt solution, the specimens being lowered automatically into the solution for a period of 1 min. in every 13 min.

(*b*) Continuous exposure of the specimens for a fixed time each day to a mist of salt solution within a glass chamber.

Fatigue testing with the Amsler Vibrophore electronically powered resonance type machine.

A salt spray cabinet recently put into use to replace a brick and tile structure is lined with super-purity aluminium, with specimen trays constructed from extruded sections in Hiduminium 33. Provision is made for simultaneous testing of up to 117 sheet specimens, each measuring 10 in. × 2 in. The specimens are suspended by P.V.C. thread from glass rods arranged in a staggered pattern, so that the corrosion products of the upper specimens do not fall on the lower ones. A spray in the form of very fine mist is injected into the top of the cabinet by compressed air at 10 lb./sq. in. through four ebonite nozzles set at right angles to each other. A small negative pressure is maintained at the bottom of the cabinet in order to evacuate the mist, and the roof of the cabinet is so designed that droplets do not fall on the specimens ; there is a trap for the condensed salt solution in the centre of the base.

The specimens are subjected to the spray for one hour in the morning and one hour in the afternoon, five days per week, the corroded specimens being periodically

A 50-watt electro-mechanical oscillator designed for the determination of torsional damping capacity.

examined visually and, ultimately, loss in weight and tensile properties are determined and suitable sections examined microscopically. Other equipment in this laboratory includes a unit for testing the abrasion resistance of surface films, a pilot plant for development work in electroplating, electropolishing and anodising, and a standard paint spraying unit, whilst thermo-setting synthetic resin adhesives, marketed under the name of Hidunite, are being developed for metal to metal bonding with bond strengths up to 4,300 lb./sq. in.

The Research Foundry

The equipment of this department, which is mainly concerned with alloy development work, comprises two lift-out gas-fired pit type furnaces, capable of dealing with up to 100 lb. of aluminium alloy, and two high-frequency furnaces—one vacuum-type and one open. The facilities available allow the production of sand and die cast material and for chill and die casting a wide variety of ingot sizes which may be subsequently fabricated on a 5 cwt. hammer or on a small 8-in. diameter rolling mill.

The alloy development work includes the investigation of new alloys and a constant effort is being made to improve existing alloys by determining the effect of variations in composition, melting, degassing and casting conditions. Spectrographic standards are also cast in this department.

Metallography and Heat Treatment Laboratories

Separate grinding, polishing and etching rooms and a photographic studio adjoin the main metallography room, which is equipped with a Zeiss Neophot microscope, capable of providing visual magnification up to 1,500 × and a screen magnification up to 3,000 ×, together with low power binoculars and a number of bench microscopes.

A thermal analysis unit designed to give a constant heating or cooling rate with a very highly sensitive control is at present being rebuilt. This equipment, in conjunction with microscopic examination, will be used to assist in determining the nature of the eutectics present in alloys, and to differentiate alloy types.

An efficient heat-treatment laboratory is very necessary in the development of materials and methods of treatment. The equipment comprises an experimental rolling plant; two forced air circulation electric furnaces; three small and one large long term ageing electric muffle furnaces, and one high temperature gas-fired muffle; a gas-fired salt bath; a platinum wound electric tube furnace; and water and oil quenching tanks fitted with means of heating. The main feature of the heat-treatment laboratory is the central control panel, by means of which all the furnaces may be automatically controlled for temperature, and certain of them for time.

Mechanical Testing Laboratories

This section is equipped with a range of machines for tensile, compression, torsion and hardness testing, the latest acquisition being an Avery Self-Indicating Universal Hydraulic Testing Machine fitted with electrically-operated autographic stress-strain recorder. The capacity ranges (1·5–15 tons) can be selected instantaneously by a hand-wheel control and the machine employs high setting speeds with automatic resetting of straining unit, so that fresh test specimens can be rapidly inserted. The electrical stress-strain recorder operates from a standard type of high accuracy extensometer which is driven in synchronism with the recording drum by stepping relays. With the addition of special extension levers, the device can be operated to produce a stress-strain curve right up to the point of fracture.

A recent addition to the creep testing equipment is a 16 unit short-lever machine constructed to the design of the British Non-Ferrous Metals Research Association. The 16 units are mounted on one frame and the load, which is applied through a 5/1 lever, has a maximum value of 1 ton. A micrometer-type extensometer, sensitive to 10^{-4} in. over a 5 in. gauge length, is used for the measurement of strain, and the specimen temperature is controlled to better than $\pm 2^{\circ}$ C. by a thermostat operating on the differential expansion between the stainless steel furnace tube and an Invar rod placed outside the casing. A special loading equipment incorporating a proving ring can be fixed to each of the units in turn, so that the load-extension curve can be plotted when each test piece is first loaded. These creep units will be used principally on short duration tests up to 500 hours for preliminary assessment and sorting out of new alloy developments and of improvements to existing alloys. Other units, some of the latest N.P.L. pattern, are available for more accurate determination of creep curves.

The fatigue testing equipment includes a 30-cwt. Haigh electro-magnetic machine, a number of small rotary and flat strip bending machines, and apparatus for tests at elevated temperatures, some of the latter being of the B.N.F. rotating-load type.

An important acquisition is an Amsler Vibrophore high-frequency machine of the electronic powered resonance type, capable of applying alternating loads up to ± 2 tons with a superimposed static load of up to 1 ton in tension or compression. The working speed is high and can be selected to fall within the limits 2,400–8,000 cycles per minute. It will normally be operated at the highest frequency, enabling fatigue tests to be completed more rapidly than is possible on the older equipment used in the past. It will be used principally on cylindrical metal specimens in tension and compression, but can

Continued on page 157

The Mass Concentration of Air-borne Dusts

Use of Dimethylterephthalate as a Filter Base in its Determination

P. F. Holt, B.Sc., Ph.D., D.I.C., F.R.I.C.
(University of Reading)

Owing to its high volatility, filter pads of naphthalene tend to disintegrate when large volumes of air are sampled. The search for a new filter base material came to an end when tests on dimethylterephthalate showed it to be very satisfactory for the purpose.

THE use of volatile filter bases for the determination of the mass concentration of dusts is now an established practice. It was originally developed by Briscoe and his co-workers,[1] and was used in the Medical Research Council's survey of conditions in the South Wales coal fields.[2] The filters are prepared from highly purified naphthalene which has been passed through a 20-mesh sieve, by compressing it to a compact pad. The dust sample is taken by means of a hand pump of known stroke volume and the dust is recovered by heating the pad to a temperature of 78° C. when the naphthalene is sublimed away leaving the dust. This sample can be weighed on the micro-balance, and in some cases is large enough for micro-analysis.

Recently the design of the filter holder for the naphthalene filter has been improved and an electrical sampling pump has been developed so that samples can be taken without continuous attention by the operator.[3] This means that the volatile filter method of estimating mass concentration of dust now provides one of the easiest methods of taking samples in the field.

Search for New Filter Base

One disadvantage of naphthalene as a filter base lies in the fact that it is so volatile that filter pads begin to disintegrate if volumes of air larger than about 30 litres are sampled. Even using the modern micro-methods of analysis, volumes considerably greater than 20 litres must be sampled to obtain sufficient dust for chemical investigation, so that the naphthalene filter is ruled out as a means of collecting samples for analysis. Because of this, a search was made for a substance which was less volatile than naphthalene but was sufficiently so to be easily removed on heating. Acenaphthene was used in preliminary experiments and appeared at first to be satisfactory, but later tests showed that, when air was drawn through the pads of this material for prolonged periods, a slight degree of oxidation took place and a small but significant residue remained after sublimation. Most other substances which were used proved to be either too volatile or insufficiently volatile for the present purpose.

Courtesy of W. Edwards & Co. (London) Ltd.

Fig. 2.—Vacuum hotplate.

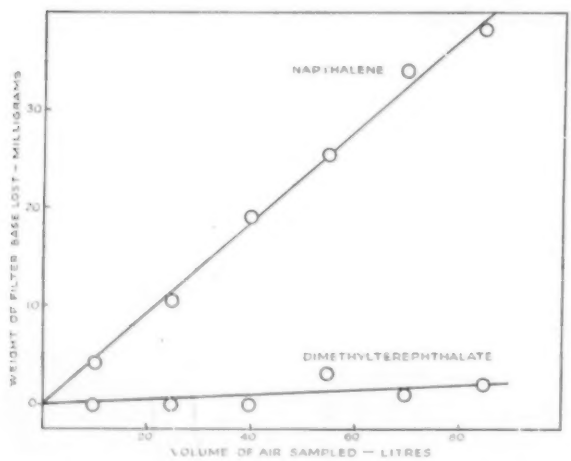


Fig. 1.—Comparative tests on dimethylterephthalate and naphthalene

Properties of Dimethylterephthalate

At the suggestion of the Research Department of Imperial Chemical Industries (Dyestuffs Division), the use of dimethylterephthalate as a filter base was

1 Matthews, Janet W., and Briscoe, H. V. A., "Volatile Solid Filters for Dust-sampling," *Trans. Instn. Min. Metall.* **44**, 111–122.
2 Briscoe, H. V. A., Holt, P. F., Spoor, N., Matthews, J. W., and Sanderson, F.M. Spec. Rep. Ser. med. Res. Coun. No. 244, 1943, 79.
3 Holt, P. F. The Determination of the Mass Concentration of Air-borne Dusts: an Electrical Sampling Pump for use with Volatile Filters. *Trans. Instn. Min. Metall.* **61**, 1951–52, part 1.

investigated. This substance proved to be very satisfactory for this purpose, and filter pads made from it were run for long periods without showing signs of disintegration. Indeed, no loss in weight could be detected after prolonged running. Comparative tests on dimethylterephthalate and naphthalene are illustrated in Fig. 1. It will be seen that while a naphthalene pad decreased in weight fairly rapidly as large volumes of air were drawn through it, dimethylterephthalate gave no indication of having lost any weight. These tests were carried out by drawing measured volumes of filtered air through the filter pads, using the electrical pump previously described, and weighing the filter at intervals.

Dimethylterephthalate is a white crystalline solid and is chemically inert under normal conditions. It has a melting point of 141° C. and sublimes rapidly, under reduced pressure, considerably below its melting point. Using suitable apparatus, these pads can be sublimed away at a temperature of about 105°–110° C. Being insoluble in water and non-hygroscopic, it is unaffected by moist atmospheres.

Dimethylterephthalate for the filter pads is purified by sublimation. It is not remelted, as is necessary when naphthalene is used, but is transferred to the filter holder in crystalline form. The filter holders and the spring loaded compressor used in preparing the filters are identical with those previously described. A compression force of 10 kg. is used in preparing the filters, and the force must be applied directly without any shearing movement of the compressor, as this produces a filter of high resistance.

Vacuum Hotplate

In an earlier communication an apparatus was described by which the filter bases could be easily sublimed away from dust samples.[4] Recently an apparatus has been developed commercially which is ideally suited for this operation. The vacuum hot plate shown in Fig. 2 is an apparatus in which objects may be heated at a controlled temperature and under reduced pressure. When vacuum is provided by means of an electrical pump (Speedivac), up to twenty samples can be rapidly handled in one run. This means that samples put into the apparatus in the evening are ready for weighing next morning. The method as now established, enables samples to be taken over long periods at constant sampling rates using an electrically-driven suction apparatus. Such samples may be large enough for microchemical analysis and may conveniently be representative of a complete working shift.

Further modifications are being attempted in the handling of filter samples with the object of their evaluation by a photoelectric method. Although these experiments are only at an early stage it would seem quite feasible to replace the method of weighing by a nephelometric method.

The author is indebted to the British Steel Founders' Association for financial assistance in carrying out this work.

4 Holt, P. F. The Determination of the Mass Concentration of Air-borne Dusts: an apparatus for the sublimation of volatile filter bases. *Trans. Instn. Min. Metall.* **59**, 1949-50, *Bull. Instn. Min. Metall.* No. 518, January, 1950.

H.D.A. Central Laboratories Revisited

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be adapted to transverse shear and torsion fatigue tests with the aid of additional gripping devices. A special furnace is being constructed which will enable fatigue testing to be carried out at temperatures up to 700–800° C., under conditions involving the combination of static and dynamic stressing. A special device will be fitted to maintain the static pre-load when plastic flow to the specimen occurs.

Physics Laboratory

This department, whose laboratory has recently been rebuilt to give a more spacious layout, has established a reputation for its work on the measurement of residual stresses by X-rays, and on damping capacity. It is possible to determine the residual stresses in a metal body of simple shape by machining tests, but these methods, besides being tedious, involve complete destruction of the components. By the X-ray method, the spacing between the planes of atoms in the crystalline structure of the metal is measured in terms of a particular wavelength of X-rays directed at the surface of the metal at the point where the stress is required. The method is also applicable to the estimation of cold working. The ancillary structure for supporting the component under examination is designed to provide a wide range of angular adjustments and the oscillating motion which is essential when applying the X-ray method to aluminium alloys. Components examined include pistons, crankcases, propeller blades and centrifugal compressors.

In addition to contributing substantially to the development of apparatus and methods for measuring damping capacity, research has been undertaken to determine the usefulness of damping capacity as an indicator of the presence of internal flaws, and to determine the magnitude and variation of damping capacity at engineering stresses for engine and structural aluminium alloys. This method has been applied to the study of the behaviour of aluminium alloys under conditions of stressing that produced fatigue. The research has shown that two phenomena, occurring either separately or simultaneously, precede failure by fatigue.

Certain types of alloy strain-harden progressively during vibration until fatigue failure occurs. At any given high level of straining, the damping capacity of such alloys decreases continuously until failure occurs. Alloys of the second group comprise, in general, age-hardening alloys brought by heat treatment to the condition of maximum mechanical strength. During vibration at high stress levels, the damping capacity of these alloys, except in some cases during the short initial period, increases continuously until fatigue failure occurs. It is probable that this phenomenon is associated with strain-induced precipitation occurring selectively in grains most susceptible to deformation by the applied stress, which may account for the fact that alloys of this type have no definite limiting fatigue stress.

800 ohms/cmf

Temp. Coeff. of Resistance:
± 0.00002 max. from -50°c to +100°c

Improved electrical resistance alloy

Higher ohmic values

Compared with certain copper-base alloys widely used for high accuracy wire-wound resistors, the electrical resistivity of Karma is exceptional, being 800 ohms per circular mil-foot, at 20° C., it is more than 2.7 times as great. Thus, Karma makes it possible to wind even smaller precision resistors at yet lower cost per ohm.

More stable resistance

The low temperature coefficient of resistance of Karma remains constant over a much wider temperature range than that of, for example, Advance (Constantan). The "useful range" of Karma is four times that of Advance (Constantan) and more than eight times that of another widely-used alloy. Therefore, Karma is especially suitable for precision resistors subjected to severe temperature changes.

Low thermal EMF

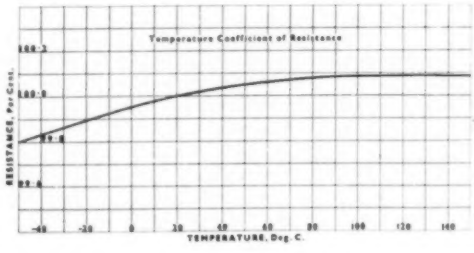
Error due to voltage generated by thermal E.M.F. against copper, in the case of Karma, is entirely negligible

High resistance to oxidation

The superior resistance of this nickel-chromium alloy, Karma, to surface oxidation enables it to retain its fine electrical properties longer than copper-base alloys.

Higher tensile strength

Besides its outstanding electrical qualities, Karma has physical advantages over the commonly accepted alloys. Its higher tensile strength permits faster winding speeds; its lower thermal expansion minimises distortion and movement in windings.



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The Preparation of Laboratory Ware in Magnesia by a Modification of the Slip Casting Technique

By H. T. Greenaway, B.Met.E. *

A modified slip-casting method is described for the preparation of magnesia refractory ware, for use in investigations into high-temperature alloys. It was developed to overcome difficulties in the normal slip-casting technique.

RECENT investigations into heat-resistant alloys for aircraft turbine engine applications have led to an increase in the use of special high-temperature refractories. The essential properties of such refractories are, briefly :—

(*a*) a high melting point ;
(*b*) resistance to thermal and mechanical shock :
(*c*) chemical inertness to the molten metal under investigation :
(*d*) freedom from impurities that may be transferred to the melt.

It has been found that suitable refractories are limited to the oxides given in Table I.

Alumina is normally used for temperatures up to 1,950° C. Beryllia can be used above the range of alumina and has excellent thermal and mechanical shock resistance, but its toxicity is such that the manufacture and use of beryllia ware are hazardous operations. Magnesia, also, is a very useful refractory above the temperature range of alumina ware. Thoria and zirconia are somewhat expensive, and their thermal shock resistance is inferior to that of beryllia and alumina.

The manufacture of refractory shapes is normally carried out by slip casting. This method has been used in the author's laboratories for the production of beryllia and alumina crucibles and thermo-couple sheaths for use in high-temperature thermal analysis. In this work, beryllia was found to be unsuitable for use as a thermo-couple sheath above the range of alumina, due to its contamination of the molybdenum-tungsten thermo-couple employed. Magnesia sheaths, however, were found to be satisfactory for this work. Thompson and Mallett[1] reported that magnesia ware was more difficult to produce by normal slip casting than were beryllia and alumina. The present paper confirms this finding and describes a simple method of producing magnesia ware by a modification of the normal slip-casting technique.

The Production of Laboratory Ware by Slip-Casting

Briefly, the method consists of pouring a suspension of plasticised refractory (i.e., a "slip") into a plaster mould having the outside dimensions of the required article plus a shrinkage allowance. After a predetermined time, during which the plaster continually absorbs water from the slip, the fluid contents of the mould are poured out, leaving a coating of semi-solidified refractory on the mould wall. This coating when removed and fired, becomes the required piece of laboratory ware.

Fig. 1.—Extraction thimbles used for casting magnesia (left) and fired magnesia ware (right).

Plasticity of refractory oxides can usually be obtained by treating the finely ground material in acid solutions. This is ascribed to a surface activation effect involving the absorption of hydrogen ions. Ionisation of the absorption complex leaves an electric charge on each particle and causes the formation of a hydrosol, which exists in a relatively soft micellar layer around each grain of oxide, and thus imparts the necessary plasticity to the mass as a whole.

The Production of Magnesia Ware

Preparation of the Magnesia "Slip"

The magnesia used was minus 150 mesh, fused refractory grade, which had to be reduced to a size suitable for slip casting. It was ground in a porcelain mill 6 in. diameter and 6 in. long containing one part (by weight) of magnesia, one part anaesthetic ether and two parts of 1 in. porcelain balls, the total volume of charge being half that of the mill. The grinding time was 16 hours at 88 r.p.m., and chemical analysis showed

TABLE I.—HIGH-TEMPERATURE REFRACTORIES

Material	Melting Point °C.	Limit of Usefulness °C.	Thermal Shock Resistance
Alumina	2050	1950	Good
Beryllia	2580	2400	Excellent
Magnesia	2800	2400	Fair
Zirconia	2700	2500	Fair
Thoria	3200	2700	Fair

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1 Thompson, J. G., and Mallett, M. W., *J. Res. Nat. Bur. of Stds.*, 1939, **23**, 319.

that very little silica was picked up during this procedure. The use of steel ball mills was avoided, since the iron picked up could not easily be removed.

The ether was allowed to evaporate from the open mill, and the magnesia removed and covered with distilled absolute alcohol in a closed jar. Thorough mixing followed, and after standing for 48 hours and pouring off the excess alcohol, it was found that the "slip" had sufficient plasticity for casting. It contained about 85% solids.

Forming and Prefiring of Magnesia Shapes

(*a*) *Into Plaster Moulds.* Attempts were made to slip cast this magnesia as has been done with beryllia and alumina, but the "green" magnesia slip could not be satisfactorily removed from the plaster mould. Various techniques of removal, including variation of magnesia particle size and plasticity, and heating of the moulds containing the slips to temperatures up to 1,000° C. were tried without success.

(*b*) *Into Double Weight Seamless Extraction Thimbles.* Casting of the above "slip" into double weight seamless paper extraction thimbles (made by W. R. Balston, Ltd.) was found to produce "green" magnesia slips of suitable thickness. The technique of casting was that used in forming alumina and beryllia in plaster moulds. The slip and thimble were then placed in a prefiring furnace and heated to 1,300° C. in about 5 hours, followed by slow cooling. The thimble was burnt off during this heating, leaving the magnesia ware in a suitably prefired condition. Cracking was sometimes found to occur on prefiring slips which had been allowed to stand overnight in air, but not in those which had been heated immediately after forming. This was attributed to some effect of atmospheric moisture, and agrees with the findings of Thompson and Mallett.[1]

(*c*) *Into Single Weight Extraction Thimbles.* The absorption of single weight extraction thimbles was found to be insufficient to form a cast of required thickness. However, they can be successfully used when backed by plaster-of-paris. Prefiring at 1,000° C. burns out the paper thimble and cracks the plaster sufficiently for it to be removed from the prefired magnesia ware. This method produced ware of the same quality as that made in double weight paper, but was not normally used because the latter method is the simpler of the two.

Firing the Magnesia

The prefired or "biscuited" magnesia shapes, produced as above, were quite porous. However, they had sufficient strength to be handled quite readily, and they were amenable to mechanical cutting. The final operation in their manufacture was firing at 1,900°–2,000° C. in a graphite crucible heated by high-frequency induction. The times of heating, soaking at temperature, and cooling were approximately 30 minutes each.

Cracking of the crucibles and sheaths so produced was rarely encountered. They have excellent mechanical strength and have withstood molten chromium alloys at 2,100° C. without penetration. Fig. 1 shows magnesia ware produced by the above technique together with the thimbles into which they were cast.

Discussion and Conclusions

The technique described is simpler and quicker than normal slip-casting procedure, in that the making of metal formers and plaster moulds is eliminated when standard paper thimbles can be used. However, its main advantage is that the difficult operation of removing the cast refractory shape from the mould is eliminated. The shape and size of commercially produced paper thimbles are somewhat limited, and these control the dimensions of refractory ware which can be readily produced by this technique, although it should be possible to make a suitable paper shape of any required dimension.

Acknowledgments

This work was carried out as part of the high-temperature metals programme of the Aeronautical Research Laboratories, Department of Supply. The author's thanks are due to the Chief Scientist of the Department for permission to publish this paper. Thanks are also due to Mr. D. G. Elliot, formerly of these laboratories, for valuable assistance in this work.

Symposium on Analytical Chemistry

Preliminary Notice

Under the auspices of the Midlands Society for Analytical Chemistry a short Symposium on Analytical Chemistry, dealing with fundamental theory and original methods, will be held at the University of Birmingham on September 10th, 11th and 12th, i.e., immediately following the International Congress on Analytical Chemistry at Oxford. Details will be announced later.

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